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Assessment of Environmental Impact of the Mineral Mining Industry

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This report presents a multimedia (air, liquid and solid wastes) environmental assessment of the domestic mineral mining industry. The primary objective of the study was to identify the major pollution problems associated with the industry. A secondary objective was to define research and development needs for adequate control of air pollutants and liquid and solid wastes connected with minieral mining. This study provides the EPA with 1) an initial data base on the type and quantity of wastes generated and the treatment and disposal techniques now applied for their control; 2) a data base for technical assistance activities; and 3) the necessary background information to implement research and development programs, to document effective pollution control techniques, and to fill gaps in the data base.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollution impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents a multimedia (air, liquid, and solid wastes) environmental assessment of the domestic mineral mining industry. The primary objective of the study is to identify the major pollution problems associated with the industry. A secondary objective is to define research and development needs for adequate control of air pollutants and liquid and solid wastes connected with mineral mining. This study provides IERL-Ci with 1) an initial data base on the type and quantity of wastes generated and the treatment and disposal techniques now applied for their control; 2) a data base for technical assistance activities; and 3) the necessary background information to implement research and development programs, to document effective pollution control techniques, and to fill gaps in the data base.

For further information the Resource Extraction and Handling Division can be contacted.

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EXECUTIVE SUMMARY

PROJECT OBJECTIVES

The overall objective of this multimedia environmental assessment of the domestic mineral mining industry is to identify potential problem areas. A secondary objective is to define research and development needs for adequate control of air pollutants and liquid and solid wastes connected with mineral mining. This study provides IERL/Cincinnati with 1) an initial data base on the type and quantity of wastes generated and the treatment and disposal techniques now applied for their control; 2) a data base for technical assistance activities; and 3) the necessary background information to implement research and development programs, to document effective pollution control techniques, and to fill gaps in the data base.

The minerals/metals of concern in this report are separated into four main categories: 1) nonmetals, 2), nonferrous metals, 3) nonferrous metals that are by-products of the smelting and refining of other metals, and 4) nonferrous metals that are primarily imported.

Nonmetals: Nonmetals, or construction materials, are almost always mined as the only recoverable constituent of an ore; however, some coproducts/by-products are associated with these minerals. Included in this category are

Dimension stone
Crushed stone
Construction sand and gravel
Industrial sand
Gypsum
Asphaltic minerals
Asbestos and wollastonite
Lightweight aggregate minerals
 (perlite, pumice, and vermiculite)
Mica and sericite

Nonferrous Metals: The nonferrous metals in this category are usually mined as the primary or major constitutent of an ore, but they can also be mined as a coproduct or by-product of other minerals. Included in this category are

Aluminum
Antimony
Beryllium
Copper
Gold
Lead and zinc
Magnesium
Mercury
Rare earth elements
Silver
Titanium

Nonferrous Metals (Smelting and Refining By-products): These nonferrous metals are not mined for their own economic value, but are constituents of an ore mined for a more economically attractive metal such as copper or zinc. These metals are not separated from ores during beneficiation; they are recovered as by-products during the smelting and/or refining of other metals. Included in this category are

Bismuth
Cadmium
Gallium
Germanium
Hafnium
Indium
Selenium
Tellurium
Thallium
Zirconium

Nonferrous Metals (Imports): These nonferrous metals are not recovered from domestic ores; they are either imported in a finished or semifinished form or are produced from imported raw ores. Included in this category are

Arsenic
Cesium
Platinum-group metals
Radium
Rubidium
Scandium
Tin

The scope of this project encompasses surface and underground mining operations and related beneficiation operations (e.g. screening, crushing, storage) normally performed at the mine site. The scope does not cover operations such as smelting and refining, which are typically performed away from the mining site.

Pollutants resulting from the various extraction and beneficiation operations are shown on process flow diagrams. When possible, wastes are identified with specific sources (i.e., dust from primary crushers or wastewater from scrubbing operations); however, in certain instances it is necessary to report a waste stream as a composite of pollutants. Pollutants in these waste streams are identified and chemically and physically characterized whenever possible, with special emphasis on potentially hazardous contaminants. In this study, "potentially hazardous contaminants" is used to identify wastes that may pose a serious threat to the environment. This identification is based on the contractor's investigation and professional judgment and does not necessarily concur specifically with the EPA hazardous waste listing under Section 3001 of the Resource Conservation and Recovery Act 1976. Of necessity, the terminology is broadly applied to widely differing types of waste streams.

PROJECT APPROACH

Data base investigations not only provide the necessary background information for a starting point, but also establish opportunities and limitations for developing a realistic and usable document. At the outset of this study it was found that data were extremely limited relating directly to multimedia wastes (air, water, solids) in the mineral mining industry; therefore, much effort was expended to obtain and record as much information as practical concerning mineral mining wastes, the control of these wastes, and the need for research and development (R&D). This was accomplished in three tasks.

The first task involved a literature search to gather, review, and compile all available information (published and unpublished) dealing with pertinent areas in the mineral mining industry. Because it was evident from the start that data relative to certain subject areas would be scarce, sources closely related to those areas were also explored. Two and a half months were spent reviewing numerous references from a variety of sources: the Hamilton County Public Library and libraries belonging to PEDCo Environmental, Inc., the Colorado School of Mines, and the University of Cincinnati; a National Technical Information Services (NTIS) data base search performed at the Science Information Retrieval Center at the University of Cincinnati Chemistry Biology Library; and the files of various local, state, and Federal agencies.

The second task involved contacting various EPA contractors now working on projects dealing with any areas related to mineral mining to identify, collect, and record the latest available information on mineral mining waste control technology and corresponding R&D needs. Two such contractors were Calspan Corporation and Monsanto Research Corporation.

The third and major task involved contacting several offices of the Bureau of Mines (BM), industrial trade associations, and specific mineral mining industries. Much valuable information was acquired from these sources in the following manner: BM offices and industrial trade associations were initially contacted by telephone; meetings were held with the Directors and/or environmental committees of the BM offices and trade associations that had indicated they could provide useful information. The next step involved visits to facilities considered by the BM and/or the associations to be representative of an industry. In instances where needed information was not available from the BM or from trade associations, visits were made to facilities suggested by prominent corporations within an industry.

The following BM offices were contacted by phone and/or letter:

U.S. Bureau of Mines, Mineral and Materials Research
Department, Washington, D.C.

- Benjamin Petkof (beryllium)
- Gertrude Greenspoon (arsenic)
- Keith Harris (cesium, rubidium, tin)
- Jim Jolly (rare earths, scandium)

U.S. Bureau of Mines Research Center
Spokane, Washington

- Roy Soderberg

U.S. Bureau of Mines Research Center
Salt Lake City, Utah

- Steve Wilson
- Joe Bilbrey
- Parky Brooks
- Don Seidel

U.S. Bureau of Mines, Liaison Office

- Paul Fillo

U.S. Bureau of Mines, Research Center
Reno, Nevada

- R. E. Lindstrom

Colorado Division of Mines, District Inspector

- Bernie Javernick

The following BM offices were visited:

U.S. Bureau of Mines Research Center, Spokane, Washington - Talked with the director of the center.

U.S. Bureau of Mines Research Center, Salt Lake City, Utah - Talked with the director of the center and with several of the research metallurgists.

Colorado Division of Mines - Acquired information from the District Inspector, who also accompanied PEDCo personnel on several site visits.

In general, the Bureau Centers could provide little information regarding the quantity of specific air, liquid, and solid wastes associated with the extraction and processing of nonferrous and construction minerals. They did, however, provide considerable information regarding process descriptions, major waste problems by industry, control techniques, and R&D projects now under way at the various centers.

Sixteen industrial trade associations were contacted by phone and/or letter:

Northwest Mining Association
Colorado Mining Association
American Mining Congress
International Lead & Zinc Research Organization
Mining and Metal Society of America
The Indiana Limestone Institute of America
National Sand & Gravel Association
Gypsum Association
National Crushed Stone Association
Mica Industry Association
Vermiculite Association
Asbestos Textile Institute
Flexible Pavements, Inc.
Cultured Marble Institute
Building Stone Institute
Perlite Institute

Four trade associations were visited:

Northwest Mining Association (NWMA) - Talked with the director of the association. Also, several PEDCo employees attended the NWMA annual convention.

Indiana Limestone Institute of America - Talked with the Director of the Institute.

National Sand and Gravel Association (NSGA) - Talked with the Director of Environmental Affairs. Also, several PEDCo employees attended the meeting of the Environmental Committee at NSGA's annual convention.

Gypsum Association - Acquired information from the Director, who accompanied PEDCo personnel on several site visits.

Trade associations were generally unable to provide specific quantitative or qualitative information regarding waste residuals generated by mineral mining and processing. They did, however, provide considerable input on process descriptions, the major waste problems of specific industries, and current waste treatment/control technologies. In some instances, they also furnished information about planned R&D programs.

Selected associations were asked to suggest several facilities representative of their industry, and conducted tours were arranged. Visits were also made to several facilities suggested by prominent corporations within an industry. For several industries, PEDCo's in-house experience and comprehensive information acquired from other companies/agencies precluded the need for visits to industry sites. The following is a list of those plants that were visited.

Dimension Stone

- Indiana Limestone Company, Bedford, Indiana

Gypsum

- United States Gypsum Company, Shoals, Indiana
- National Gypsum Company, Shoals, Indiana
- National Gypsum Company, Sun City, Kansas

Perlite

- Grefco, Inc., Antonito, Colorado

Beryllium

- Brush Wellman, Salt Lake City, Utah

Lead-Zinc-Silver

- Hecla Mining Company, Wallace, Idaho
- Homestake Mining Company, Crede, Colorado

Rare Earths, Titanium, Zirconium, Hafnium

- Humphrey's Mining Company, Folkston, Georgia

The industry contacts/visits provided some rough estimates of air, water, and solid waste materials associated with the mineral mining industry, but most information was scanty and of a site-specific nature. These contacts were helpful to PEDCo in that they provided an insight into the general attitude and philosophy of the mining industry toward control/treatment of wastes. PEDCo also derived from these contacts/visits valuable recommendations concerning R&D needs in the mineral mining industry.

In addition to the sources of secondary information already named, PEDCo also contacted several state pollution control agencies and EPA regional offices regarding waste problems and their control in the mineral mining industry. Considerable data were acquired on quantities of waste, applicable control techniques and efficiencies, and process descriptions.

The information obtained from all these sources was tabulated and summarized into a data base report to support the preparation of this document.

WASTE CHARACTERISTICS AND CONTROL

Sources of atmospheric emissions and liquid and solid wastes are numerous in the mineral mining industry. Pollutants generated from these sources may or may not contain potentially hazardous materials; however, uncontrolled wastes from the mining and processing of ores can cause serious environmental damage whether they contain hazardous contaminants or not. Although state-of-the-art technology is now available to abate atmospheric emissions and liquid and solid wastes associated with the mineral mining industry, too often such technology is not applied, particularly at smaller facilities where the value of the end product is too low to make controls economically feasible.

Control and treatment technologies that are assessed and evaluated throughout this report fall into one of the following categories:

1. State-of-the-art technology that is now widely practiced in the mineral mining industry.
2. State-of-the-art technology that is available and viable, but is not commonly practiced in the mineral mining industry.

Both in-plant and end-of-process technologies are identified in the discussions, as are the limitations, problems, efficiencies and reliability of each control or treatment (when known). The effects of the application of various technologies on other pollution problems (e.g. ultimate disposal of particulates entrapped by dry collection devices or ultimate disposal of sludges generated by wet scrubbers) are also identified.

Air emissions and liquid and solid wastes generated by the mineral mining industry are briefly summarized in the following paragraphs. Related control and treatment technologies are also mentioned.

Particulates from various phases of the mining process and from any on-site beneficiation processes comprise the primary air pollution in the mining industry. Emissions emanate from either fugitive or process sources. For the purpose of this report, fugitive emissions are defined as "particulate matter which escapes from a defined process flow stream due to leakage, materials charging/handling, inadequate operational control, lack of reasonably available control technology, transfer or storage." Process point emissions are those emitted from a definable point source, such as a stack. Particulates emanating from process and/or fugitive sources (such as free silica from sand and gravel operations and asbestos from asbestos mining and processing) can pose health hazards. Particulates can also be aesthetically displeasing or annoying to the public. Control of particulate emissions involves a variety of techniques. Dust suppression techniques, designed to prevent particulate matter from becoming airborne, can be used on both fugitive and process sources. Various dry and wet collection systems (fabric filters, scrubbers) are used where particulates can be contained and captured.

Liquid wastes generated by the construction materials and nonferrous metals industries differ in one major way: construction materials operations generate effluents that normally contain only suspended inert solids, whereas nonferrous metals mining and processing facilities generate acidic discharges that usually contain dissolved heavy metals. Liquid wastes associated with the mineral mining industry can be separated into three major categories: 1) mine dewatering (mine pumpout from surface and underground mines); 2) process wastewaters (spent waters used in transportation, classification, washing, separation, and processing of ores); and 3) surface runoff (precipitation that falls onto mine and mill properties and has the potential of traveling overland to surface water systems or percolating into aquifers). Leakage from tailings ponds and incidental water used for such purposes as machinery cooling and dust supression are also sources of water pollution. Mine dewatering and surface runoff, the major sources of liquid waste at many operations, are also often the most difficult to control and treat. Wastewaters from these two sources can be extremely detrimental to aquatic life, especially if they contain heavy metals. Most liquid wastes from processing operations range from alkaline to neutral and have a high slurried solids level. These wastes may contain metal ions, reagents such as cyanide, and high levels of dissolved solids. They are normally discharged to tailings ponds, where the supernatant is treated before it is recycled or discharged to receiving streams. The treatment, however, is often insufficient to prevent degradation of the receiving waters. Settling ponds or lagoons are used most commonly to treat effluents from mining and beneficiating operations. These ponds remove suspended solids and allow for pH control. Some operators use flocculating agents to facilitate settling. Secondary treatment methods such as clarifiers, supernatant and/or process wastewaters.

Overburden and gangue are the major solid wastes generated by the mineral mining industry. The solid wastes (tailings) generated during beneficiation consist primarily of host rock material. Other solid wastes are produced from wastewater treatment (sludges from settling pond dredging and dewatering devices) and air pollution control systems (particulates collected by fabric filters and scrubbers). The treatment and control of solid wastes usually involves disposal into off-site landfills, on-site disposal (impoundment on the surface or returning the solids to the mine), and, in a few instances, recovery of the solids as a by-product. On-site disposal of solids can cause other pollution problems, such as runoff, seepage, and fugitive dust.

ENVIRONMENTAL INDEX

An environmental index was prepared using the information assimilated during the multimedia assessment of the mineral mining industry. It consists of a tabulation of the sources, types, and amounts of atmospheric emissions and liquid and solid wastes associated with the mining and processing of construction materials and nonferrous metals. The information contained in the environmental index tabulations reflected the conclusions we reached concerning research and development needs.

CONCLUSIONS AND RESEARCH AND DEVELOPMENT NEEDS

Dimension Stone

The environmental impact from this industry is relatively minor. Conventional methods are sufficient to control atmospheric emissions and liquid and solid wastes. Other than an investigation of the feasibility of making bricks from the sludge from the sawing and finishing operations, no research is recommended.

Crushed Stone

Technologies currently applied in the crushed stone industry are adequate to maintain environmental standards. The only research recommended involves locating a steady market for the sludge from the settling ponds and the particulate matter collected by the fabric filters.

Construction Sand and Gravel

Although many sand and gravel operators are maintaining good pollution control programs, some environmental problems still persist. The major problems involve 1) dewatering settling pond sludge, which consists of colloidal fines; 2) the disposal of dewatered waste fines; 3) the silt load from storm runoff and pit pumpout from part-time or temporary sand and gravel operations; 4) contamination of ground water resulting from seepage and percolation from settling basins; and 5) the introduction of large amounts of suspended solids into public waterways during dredging operations.

In connection with problem 1), research is needed to determine the properties in colloidal particles that make the slime so difficult to dewater, and to develop an economical mechanism for dewatering this material. Research concerning problem 2) should be aimed at determining the effectiveness of waste fines (with or without additives) as a soil builder or fertilizer and to find other uses, such as building bricks and road base filler. An important part of this research effort is to find markets for possible by-products in the immediate vicinity of the sand and gravel plants. For problem 3) research efforts should be concentrated on determining the practicality of constructing diversion ditches and/or retaining dikes to contain and control runoff at temporary facilities. In connection with potential ground water contamination as a result of problem 4), an evaluation should be made of the nature and extent of seepage/percolation from settling ponds, followed by research relating to possible preventive measures. To provide an answer to problem 5), research should be initiated to find an effective and economical means of removing or containing suspended solids generated from dredging operations.

Industrial Sand

The problems are the same as those in the construction sand and gravel industry, and the same research recommendations apply.

Gypsum

Gypsum is mined and beneficiated by environmentally acceptable methods, and no hazardous pollutants are generated. State-of-the-art control technologies are applied to contain air emissions, and liquid wastes are completely recycled as process water. The only area for possible research is the disposal/utilization of overburden and waste rock materials removed from open-pit mines.

Asphaltic Minerals

This industry appears to cause no serious pollution problem, partially because of its small size and the location of its mines in remote dry areas. If, however, the vague boundary between oil shale and asphaltic minerals becomes even more vague and the deposits become of value as a fuel source, the industry could expand both geographically and in size. When and if that occurs, research will be needed to quantify specific waste streams.

Asbestos and Wollastonite

Asbestos has recently been recognized as a potential carcinogen, and asbestos fibers can be liberated into the air in dangerous amounts at all stages of mining and beneficiation of the ore. Because of the carcinogenic properties of this mineral, research should be directly related to reducing adverse health effects.

The one wollastonite mine in the United States does not warrant research and development effort.

Lightweight Aggregate Minerals

Other than the usual problem of judicious disposal of overburden and consideration for the ultimate condition of the abandoned mine site, the major problem associated with lightweight aggregate mining and beneficiation has to do with the generation of large quantities of fines. The fines are collected by dry dust collection devices, but they still present a solid waste disposal problem. Some fine particulates are returned to the process or sold as a by-product, but most have no use and must be disposed of onsite. Research should be aimed at developing a market for these fines.

Mica and Sericite

Very little mica and sericite are mined in the United States, so the environmental impact from this industry is minor. Conventional state-of-the-art techniques are sufficient to control major pollutants. However, two areas for research do exist. One involves an investigation into the feasibility of recycling the large quantities of treated effluent resulting from the flotation process, and the other concerns an alternative to water for controlling fugitive dust during periods when the ambient temperature falls below freezing.

Aluminum

Available techniques of land reclamation and lime treatment of mine runoff are adequate to maintain environmental standards in the bauxite mining and beneficiation industry, and air emissions are also easily controlled. One promising area for research, however, involves reducing the volume of water produced by the mining operation. Groundwater control techniques now being used to increase the stability of open-pit slopes should be expanded to minimize the production of acid mine discharge. This will require an investigation of the use of gravity wells and drains.

Antimony

Pollution problems from the mining of antimony in the United States are insignificant because of the small quantities involved. Hence, no areas of research are recommended.

Beryllium

The beryllium industry in this country is relatively small. Because of the proprietary nature of some of the processes and the fact that only one mine is currently in operation, a complete environmental assessment is impossible. Wastewater is impounded, and solid waste is blended into the topography during reclamation. The only area that might be worthy of research is the extent to which impoundments prevent leakage.

Copper

Fugitive dust control, large volumes of tailings (often containing hazardous materials), the control of wastes from the flotation process, the amount of solid waste created by using ponds to settle the tailings from the flotation system, the use of sodium cyanide as a flotation depressant, and reclamation of inactive tailings by revegetation or stabilization are all areas of concern in the copper industry. Research and development activity is suggested in each of these areas.

Fugitive dust control provided by water is of a very temporary nature; therefore chemical stabilizers are used. Some comparative studies of the more than 1000 proprietary stabilizers now available would be of value.

The danger of heavy metals leaching into groundwater from unlined tailings ponds is always present. Techniques should be researched either to remove the heavy metals from the tailings or to seal the ponds to prevent leaching.

Tailings are commonly removed from flotation water by allowing them to settle in a pond. If mechanical screening and filtering equipment could be developed to separate tailings from concentrator water, it would permit more effective control of this solid waste.

Cyanide that enters a copper mill tailings pond is stable in solution because the pH of the pond water is above 8; therefore, cyanide escapes with any seepage that occurs. The development of an alternative reagent to replace sodium cyanide as a flotation depressant would eliminate this risk.

Many times the pH and associated parameters of copper tailings are such that they present obstacles to revegetation and stabilization of inactive tailings. Research and development of soil binders and vegetation with a broad pH-range tolerance would be beneficial.

Gold

Most of the wastewater from gold mining and beneficiation operations is discharged into a tailings pond, then recycled to the mill or discharged into a watercourse. Solid waste is usually discarded into the same pond. These solids could contain gold or other recoverable minerals. One area of research could concentrate on reclamation of solids that settle out in the tailings pond. The other possible area of research involves finding an economical method of controlling the wastewater, which contains arsenic and cyanide.

Lead and Zinc

The problems and suggested areas of research and development are much the same as those for the copper industry.

Magnesium

The magnesium mining and beneficiation industry causes fewer environmental impacts than most other chemical industries. The following are possible areas for research and development programs, however. Efforts could be made to characterize the feed streams for the possible presence of unknown contaminants that could be creating significant public health impacts. Sufficient potentially hazardous chlorine is emitted to the atmosphere to be detected by smell in the immediate vicinity. Research efforts may be focused on reducing or controlling these emissions.

Mercury

The mercury industry is comparatively small in the United States, and the location of the mines in remote areas of arid climate tends to minimize the environmental impact. The most significant problem for research is the control of hazardous mercury vapor from open deposits. Wastewater from mining and processing of the ore can be recycled; however, the potential is great for release of mercury to the environment through impoundments. For this reason, research is also needed to develop an efficient method of removing mercury from water.

Rare Earth Elements

The rare earth mineral mining industry is not considered a source of adverse environmental impacts. One possible area of research would be to develop a means of recycling or disposing of the large quantities of overburden waste that rare earth mining is projected to produce as the industry expands.

Silver

Liquid wastes create the largest pollution problem in the silver mining industry. The irregular terrain of the arid areas in which most mines are located make treatment by tailings ponds difficult at best, and the scarcity of water makes it essential to recycle as much as possible. Also, because silver is mined in conjunction with several other minerals, separation is accomplished by a series of flotation cells, and many reagents are accumulated in the final wastewater. This makes the recycling of flotation water difficult.

Research could be aimed at finding an economical way to recover or separate the reagents from the wastewater or the development of degradable reagents that naturally deteriorate after a short period of time. Another research possibility is the combining of liquid wastes from several adjacent mines into one large reverse-osmosis treatment facility. Collateral research into managing the the resulting slurry and solid waste disposal problem may be undertaken.

Titanium

The size of the industry and the available solutions to any pollutant control problems that are likely to develop preclude the necessity of any research and development activity.

Nonferrous Metals (Refinery/Smelter By-Products)

Since these metals are recovered as smelter or refinery by-products of ores that are mined for more economical attractive metals, any research and development needs would be included under the primary metals.

Nonferrous Metals (Imports)

Because these metals are either imported in a finished or semifinished form or are produced from imported raw ores, their extraction does not pose an environmental hazard in the United States.

ESTABLISHMENT OF R&D PRIORITIES

Because of the large number of mining industries covered in this report, a system was developed to determine priorities for purposes of research and development needs. Ten criteria were chosen to provide EPA with a means to judging R&D needs for each industry (Table 1). Each criterion was weighed and listed in the order of its relative importance. Thus Criterion 1 is the most important and Criterion 10 is the least. Three or four arbitrary values are assigned within each criterion to indicate the degree to which that criterion applies to each industry. For example, Criterion 1 deals with hazardous wastes generated by mining and beneficiation. If a specific industry generates little or no hazardous wastes, it receives a basic value of 5 for that criterion; if hazardous wastes are a minor problem, it receives a value of 10; if hazardous wastes are a major problem, it receives a value of 80. Because the first five criteria are considered critical as far as potential problems are concerned, they are promising areas for research.

Various factors entered into the selection and rating of all the criteria. For example, the generation of hazardous waste by an industry is assumed to be the criterion of prime importance in the establishment of R&D priorities because of the environmental threat (lethal or sublethal) posed if such wastes are not controlled. Although the control of nonhazardous atmospheric emissions and liquid and solid wastes is considered necessary in the mining industry, the environmental threat of these wastes is not of the magnitude as that of hazardous wastes and the values assigned to them are not as high.

The quantity of ore mined by a particular industry is also a criterion, as it is directly related to the amount of waste generated by that industry. The future of each industry is also important in determining R&D needs. If projections indicate a decline in an industry, the need for research and development is not as great as it would be for industries for which increased activity is projected and thus the generation of more waste materials.

TABLE 1. IMPACT PRIORITIES FOR R&D

Criteria	Impact Intensity				
	A	B	C	D	E
1. Hazardous materials associated with mining and beneficiation	None to low (5)	Minor (10)	Moderate (20)	Significant (40)	Major (80)
2. Degree of control - atmospheric emissions	85-99% (4)	80-84% (8)	65-79% (17)	34-64% (36)	0-33% (75)
3. Degree of control - liquid wastes	85-99% (3)	80-84% (6)	65-79% (14)	34-64% (32)	0-33% (70)
4. Degree of control - solid wastes	85-99% (2)	80-84% (4)	65-79% (11)	34-64% (28)	0-33% (65)
5. Domestic ore production	0-300 Gg (1)	301-500 Gg (2)	501-2,700 Gg (8)	2701-5000 Gg (24)	>5000 Gg (60)
6. Growth of the specific mineral	Decline (0)	Stable (0%) (0)	0-5% (5)	6-24% (20)	>25% (55)
7. Number of domestic mines	<10 (0)	11-24 (0)	25-100 (2)	101-999 (16)	>1000 (50)
8. Number of principal producing states	0 (0)	1 (0)	2 (0)	3-4 (12)	>4 (45)
9. Total number of producing states	0 (0)	1 (0)	2 (0)	3-9 (4)	>10 (35)
10. Present degree of information on the industry	Info. complete (0)	Minor gaps (0)	Moderate gaps (0)	Significant gaps (4)	Major gaps (30)

(continued)

TABLE 1. (continued)

Mineral/Criteria	1	2	3	4	5	Critical Score[a]	6	7	8	9	10	Total Score[b]
Nonferrous Metals												
Aluminum	20	36	14	11	24	105	5	0	12	4	0	126
Antimony	5	8	14	2	2	31	5	0	0	4	0	40
Beryllium	10	4	6	2	2	24	5	0	0	4	0	33
Copper	80	36	32	28	60	236	5	2	45	35	0	323
Gold	20	17	14	28	24	103	5	2	45	35	4	194
Lead and Zinc	80	8	14	28	60	190	5	2	12	35	0	244
Magnesium	10	36	6	2	24	78	5	0	12	4	0	99
Mercury	40	36	14	4	1	95	0	0	12	4	0	111
Rare Earth Elements	5	8	6	2	1	22	5	0	12	4	0	43
Silver	20	17	32	28	8	105	5	16	12	35	0	173
Titanium	20	17	6	11	8	62	5	0	12	35	0	114
Nonmetals												
Asbestos and Wollastonite	40	17	14	11	2	84	5	0	12	4	4	109
Asphaltic Minerals	10	17	14	28	2	71	0	0	12	4	4	91
Construction Sand & Gravel	10	4	6	11	60	91	20	50	45	35	0	241
Crushed Stone	5	17	14	11	60	107	5	50	45	35	0	242
Dimension Stone	5	8	14	11	8	46	0	16	45	35	0	142
Gypsum	5	8	6	28	24	71	5	2	45	35	0	158
Industrial Sand	10	4	14	28	8	64	5	16	45	35	0	165
Mica and Seriate	5	4	3	4	1	17	0	0	12	4	4	37
Perlite	5	36	3	28	8	80	20	0	0	4	4	108
Pumice	5	36	3	28	24	96	5	16	45	35	4	201
Vermiculite	10	4	6	28	1	49	20	0	0	0	4	73
Nonferrous Metals (refinery/smelting by-products[c])	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nonferrous Metals (imports)[d]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

(continued)

TABLE 1. (continued)

[a] Critical score provides an indication of the combined effects of potential hazard, degree of environmental control, and extent of ore volume for particular minerals.

[b] Total score provides only a general indication for ranking. Specific attention should be given to the ten criteria. For example, if it was desired to identify 3 ranking minerals associated with mining and beneficiation, copper; lead and zinc; and, crushed stone would yield the highest relative ranking. Yet there is a wide variation of both critical and total scores of each. Similarly, if impact from the mineral represented by the largest number of mines was sought, construction sand and gravel or crushed stone may be selected.

[c] Several nonferrous metals covered in this report are not mined for their own economic value, but are constituents of an ore that is mined for a more economically attractive metal such as copper or zinc. These metals are captured during the refining or smelting of ores containing other metals. The following is a listing:

Bismuth
Cadmium
Gallium
Germanium
Hafnium
Indium
Selenium
Tellurium
Thallium
Zirconium

[d] Several nonferrous metals covered in this report are not currently mined in the United States. These metals are either imported in a finished or semifinished form or are produced from imported ores; therefore, their extraction does not pose an environmental hazard to the United States. These metals are as follows:

Arsenic
Cesium
Platinum-group metals
Radium
Rubidium
Scandium
Tin

The number of domestic mines, the principal producing states, and the total number of producing states are important criteria in that the wider the geographic distribution of an industry, the more widespread will be the pollution problems associated with that industry and the greater need for control.

The amount of data available on each industry is a necessary criterion for several reasons. Lack of understanding regarding an industry's process means a lack of knowledge about its waste streams; and the less that is known about the waste streams, the greater the possibility that hazardous and nonhazardous waste streams are either inadequately controlled or completely uncontrolled.

After values have been assigned to each criterion, the values of a particular industry are totaled. A comparison of industry totals then provides a partial guidance for determining R&D efforts (Table 1).

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METRIC-TO-ENGLISH CONVERSION TABLE

To convert	To	Multiply by
Hectares	Acres	2.471
Cu. meters	Cubic feet	3.531×10^{1}
Cu. cms/sec	Cubic feet/min.	2.119×10^{-3}
Cu. meters	Cubic yards	1.308
Meters	Feet	3.281
Cu. meters	Gallons	2.642×10^{2}
Centimeters	Inches	3.937×10^{-1}
Kilometers	Miles (statute)	6.215×10^{-1}
Kilograms	Pounds	2.204
Megagrams	Tons (short)	1.106
Liters	Gallons	2.642×10^{-1}

SECTION 1

INTRODUCTION

This report presents a multimedia environmental assessment of mineral mines producing nonferrous metals and construction materials. This assessment encompasses the identification of wastes and waste sources, quantities, and characteristics, as well as applicable control technology. An Environmental Index summarizes the wastes and the waste sources, quantities, and characteristics for each mineral.

The nonferrous metals and construction materials included in the study are listed in Table 2. The mining processes covered are ore extraction and those mine-site beneficiating operations that prepare the minerals for shipment as salable products or as raw material for final processing. Final processing operations such as refining, smelting, and exfoliation, which are located away from mine sites are not considered in this report.

Many of the nonferrous metals are commonly found in association in the same ore. For example, some complex copper ores yield not only copper but also selenium, tellurium, gold, silver, and other nonferrous metals. Among nonferrous metals that are not mined for their own economic value are bismuth, cadmium, gallium, germanium, hafnium, indium, selenium, tellurium, and thallium. No domestic mines operate solely for the extraction of any of these metals; rather, they are captured during the refining or smelting of more economically attractive ores like copper or zinc. Ore production statistics are therefore not presented for these metals.

Several nonferrous metals are not presently recovered from domestic ores and are either imported in a finished or semifinished form or are produced from imported raw ores. They are arsenic, cesium, platinum-group metals, radium, rubidium, scandium, and tin. Since their extraction poses no environmental hazard to the United States, they have been excluded from the discussion.

Salient production statistics for construction materials and nonferrous metals are presented in Tables 3, 4, and 5. These data were derived from Bureau of Mines publications, particularly from Mineral Facts and Problems, 1975 edition, and telephone interviews with the appropriate commodity specialists at the U.S. Bureau of Mines in Washington, D.C.

TABLE 2. SUBJECT MINERALS

1) Construction Materials

- Dimension stone
- Crushed stone
- Construction sand and gravel
- Industrial sand
- Gypsum
- Asphaltic minerals
- Asbestos and wollastonite
- Lightweight aggregate minerals
- Mica and sericite

2) Nonferrous Metals

- Aluminum
- Antimony
- Arsenic
- Beryllium
- Bismuth
- Cadmium
- Cesium
- Copper
- Gallium
- Germanium
- Gold
- Hafnium
- Indium
- Lead
- Magnesium
- Mercury
- Platinum-group metals
- Radium
- Rare-earth elements
- Rubidium
- Scandium
- Selenium
- Silver
- Tellurium
- Thallium
- Tin
- Titanium
- Zinc
- Zirconium

TABLE 3. PRODUCTION STATISTICS FOR CONSTRUCTION MATERIALS

	Domestic mine production (1974), Gg	Domestic mine production (1979), Gg	Domestic mine production (1985), Gg	Major producing states	Type of mine
Crushed stone[1,a]	944,755	817,648	1,405,850	Illinois, Pennsylvania, Texas, Missouri, Ohio	Surface, (95%) Underground, (5%)
Dimension stone[1,a]	1,737	1,273	1,361	Indiana, Georgia, Vermont, Ohio Pennsylvania	Surface, (100%)
Sand and gravel and industrial sand[2,a]	887,730	716,018	1,260,730	California, Michigan, Illinois, Texas, Minnesota	Surface, (90%) Dredging (10%)
Gypsum[3]	10,883	8,844	10,857	Michigan, California, Texas, Iowa, Oklahoma	Surface, (80%) Underground, (20%)
Asphaltic minerals	N.A.	N.A.	N.A.	Texas, Utah, Oklahoma	Surface, (70%) Underground, (30%)
Asbestos[4,a]	102	90	145	California, Arizona, Vermont	Surface, (80%) Underground, (20%)
Wollastonite[a]	W	W	W	New York	Underground, (100%)
Lightweight aggregate					
Minerals					
Perlite[5,6]	613	640	816	New Mexico	Surface, (100%)
Pumice[6,7]	3,571	3,530	5,986	Arizona, California, Oregon, Hawaii	Surface, (100%)
Vermiculite[6,8]	309	308	531	Montana, South Carolina	Surface, (100%)
Mica and sericite[9,a]					
Sheet mica[9,a]	W	.002	0		Surface, (100%)
Scrap and flake[9,a]	124	122	168	North Carolina	Surface, (100%)

[a] Information obtained via telephone conversations between PEDCo staff and personnel of the U.S. Bureau of Mines, Washington, D.C.

N.A. - Not available.

W - Information withheld.

TABLE 4. PRODUCTION STATISTICS FOR NONFERROUS METALS

Metal	1974 ore[a] production, Gg	1975 ore[a] production, Gg	Estimated 1985 ore production, Gg	% of total primary domestic metal production	Major associate metals	Major producing states	Type of mine
Aluminum[10,b]	2917	2652	2993	100	Gallium	Arkansas, Alabama, Georgia	Surface, 100%
Antimony[11,b]	Confidential	Confidential	Confidential	20	Lead, silver	Montana, Idaho	Underground, 100%
Beryllium[12,b]	Confidential	Confidential	Confidential	100	None	Utah	Surface, 100%
Copper[13,b]	244000	218000	317000	98	Gold, silver, selenium, lead, tellurium, platinum-group metals	Arizona, Utah, New Mexico, Nevada, Michigan	Surface, 80% Underground, 20%
Gold[14,b]	4200	5200	5900	55	Copper, lead, silver, platinum-group metals	South Dakota, Nevada, Arizona	Surface, 66% Underground, 33% Dredging, 1%
Lead[15,b]	8441	7854	9110	85	Antimony, bismuth, gold, silver, tellurium, zinc copper, gallium	Missouri, Idaho, Colorado, Utah	Underground, 100%
Magnesium[16,b] (product)							
Nonmetal	864	795	1273	100	None	California, Texas, Utah, Michigan	Brines, N.A. Surface, N.A.
Metal	159	166	253	100	None	Texas	Brines, N.A. Surface, N.A.
Mercury[17,b]	26	70	214	100	None	Nevada, California, Alaska	Surface, 33% Underground, 66%
Rare earth elements[18,b]	234	176	384	100	Titanium, hafnium, zirconium	California, Florida	Surface, 90% Dredging, 10%
Silver[19,b]	628	709	941	33	Copper, lead, zinc, antimony	Idaho, Montana	Underground, 100%
Titanium[20,b]	676	650	838	100	Hafnium, zirconium	New York, Florida, New Jersey	Dredging, 80% Surface, 20%
Zinc[21,b]	453	426	544	52	Cadmium copper, gallium, germanium, indium, lead, silver, thallium	Missouri, Colorado, Tennessee, Idaho, New York	Underground, 100%

[a] Represents that ore mined for designated metal where that metal is the major or primary constituent of the ore. It does not represent the tonnage of ore mined for other metals where the designated metal is a constituent of the ore and is recovered only as a by-product or coproduct.

[b] Information obtained via telephone conversations between PEDCo staff and personnel of the U.S. Bureau of Mines, Washington, D.C.

N.A. - Not available.

TABLE 5. DOMESTIC MINE PRODUCTION OF NONFERROUS METALS

	1974 domestic primary production, Gg[a]	1975 domestic primary production, Gg[b]
Aluminum	1945	1768
Antimony	0.6	0.8
Beryllium	c	a
Bismuth	c	a
Cadmium	3.023[d]	1.989[d]
Copper	1448	1282
Gallium	c	c
Germanium	0.013	0.014
Gold	0.035	0.033
Hafnium	0	0
Indium	c	c
Lead	602	563
Magnesium		
Nonmetal	864	795
Metal	159	166
Mercury	151	508
Rare earths	20.4[18]	15.3[e]
Selenium	584	325
Silver	1.05	1.09
Tellurium	173[d]	1.19[d]
Thallium	c	c
Titanium	233[20]	233[20]
Zinc	454	425

[a] Ref. 22 (except as noted).

[b] Ref. 6 (except as noted).

[c] Withheld to avoid disclosing company confidential data.

[d] Refinery production.

[e] Information obtained via telephone conversations between PEDCo staff and personnel of the U.S. Bureau of Mines, Washington, D.C.

Table 3 presents 1974 and 1975 domestic mine production figures for construction materials and projected production figures for 1985. The table also shows the leading producing states and the method of extraction. Ore tonnages are not available.

The crushed stone segment of the industry produces the largest annual tonnage of product, followed closely by the sand and gravel industry, positions they are expected to retain through this century. Since they are closely aligned to construction activity, stone and sand and gravel operations are usually concentrated near urban centers. This sometimes creates a land-use conflict with promoters of local business expansion, residential construction, and public works projects such as parks and recreation areas. Consequently, the slight but growing trend is away from open pit quarries to underground mining of these materials. As a result, subsidence may become a future environmental impact.

Growth in the construction material industries should parallel the growth in the Nation's economy with two exceptions. One is the dimension stone industry; the demand is decreasing because of the introduction of alternative construction materials such as glass and steel. The other exception is the sheet mica industry. Only 0.002 gigagram was produced in 1975, and by 1985 this country will probably no longer produce sheet mica. It is assumed that asphaltic minerals are following the normal growth pattern, although no production data are available. The same is true of wollastonite since only one company (in New York) produces this material, and its production data are confidential.

Production statistics for nonferrous metals outlined in Table 4 quantify the amount of ore mined for each metal except where such data are considered confidential by the producer. The data presented in Table 4 represent only ore in which the designated metal is the primary constituent; the table does not include the amount of ore mined for those metals where the designated metal is a coproduct or by-product. For example, in 1975, 7854 gigagrams of ore was extracted from mines in which lead was the primary metal. The table includes only the percentage that this ore contributes to the total domestic primary metal production of lead (i.e., lead ores contributed 85 percent of the total domestic lime output of lead; the remaining 15 percent was taken from lead-zinc, zinc, copper-lead, copper-zinc, or copper-lead-zinc ores). Table 4 also lists the leading producing states, the types of mines, and the associated metals for each nonferrous metal. Statistics for the production of primary metals from domestic ore are presented in Table 5.

Production statistics for beryllium are not available for publication. The Brush-Wellman, Inc., mine in Utah is the sole domestic producer of this mineral. Statistics for the primary antimony industry also are incomplete. Total domestic mine production is known, but the amount of ore processed each year cannot be determined. Although much of our domestic antimony comes from the lead-silver ores of Idaho, a substantial amount is also taken from antimony ores near Towson Falls, Montana. One Montana producer is known to extract ores solely for their antimony content, but he elects to keep production data proprietary.

Although production of most nonferrous metals declined in 1974 and 1975 because of the general economic downturn, it should return to normal levels as the economy regains its strength. Only mercury shows any signs of dramatically increasing production through 1985. This sudden surge is not a function of rising demand; rather it is directly attributable to the opening of a large mercury mine in Nevada. An annual output of 689 megagrams from this mine will greatly reduce dependence on imported mercury.

Copper producers are by far the largest extractors of nonferrous metals. The copper industry produced 218,000 gigagrams of ore in 1975 compared with 7854 gigagrams of ore processed by the lead industry, which ranks second. In terms of volume of ore, the smallest producers are the mercury industry (69.7 gigagrams in 1975) and the rare-earth group (176 gigagrams in 1975).

SECTION 2

GENERAL INDUSTRY PROCESS DESCRIPTION

Mining activities encompass prospecting and exploring for a mineral deposit through finding, proving, developing, extracting, and processing the ore. As indicated on Figure 1, which depicts the scope of activities, the mining industry can be divided into three major phases:

Phase I - Before Mining
Phase II - Mining
Phase III - After Mining

These three phases are common to the mining of both construction and nonferrous minerals, although the manner in which they are accomplished may vary.

Premining activities (Phase I) involve prospecting and exploration required to locate, characterize, and prove a potential ore body. Once proof of an ore deposit has been established, the property is prepared for ore extraction and processing. This site-development step includes trenching, drilling, clearing and grubbing, removing overburden, and constructing buildings.

Phase II refers to actual ore extraction and related simultaneous activities (e.g., blasting, loading, conveying). Extraction processes for both construction and nonferrous minerals include underground mining, surface mining (primarily open-pit), and some dredging.

Activities subsequent to mining (Phase III) involve processing and preparing the raw mineral ore for the end product or for shipment to final processing facilities. Processing normally includes operations such as size reduction, classification, concentration, leaching,* and smelting and refining. Smelting and refining are not considered in this document, since the major areas of concern are mining operations and initial beneficiation processing conducted at the mine site and integrated with mining operations (e.g., size reduction, classification, concentration).

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*Leaching involves the recovery of mineral values from rock by hydrometallurgical processes. Leaching, considered as a beneficiation method as well as a secondary mining method, is discussed in the beneficiation section of this report.

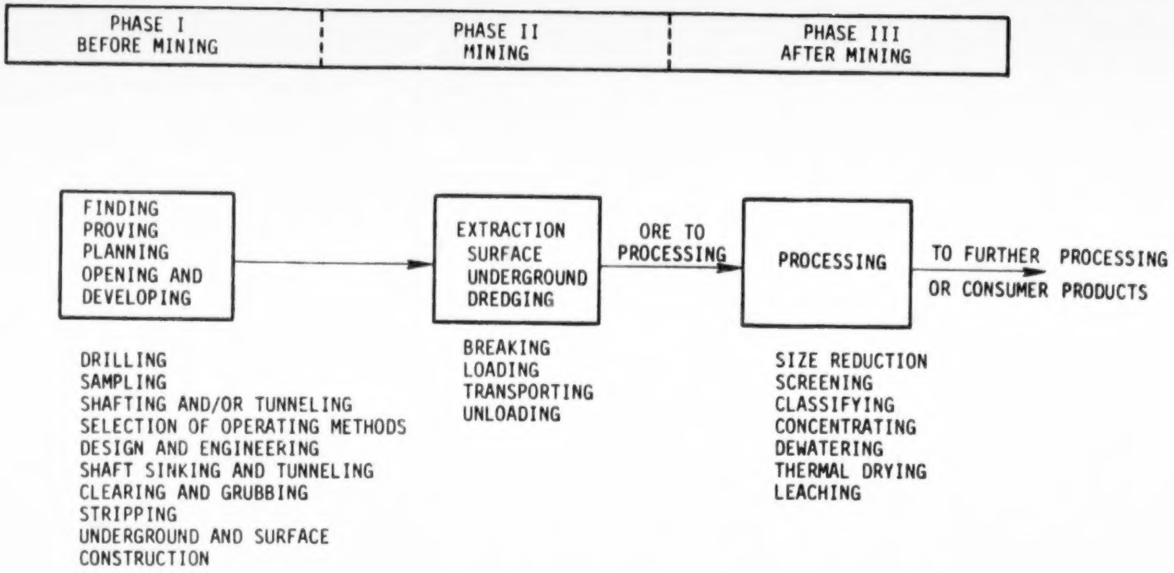

PHASE I
BEFORE MINING
PHASE II
MINING
PHASE III
AFTER MINING
FINDING
PROVING
PLANNING
OPENING AND
DEVELOPING
EXTRACTION
SURFACE
UNDERGROUND
DREDGING
ORE TO
PROCESSING
PROCESSING
TO FURTHER PROCESSING
OR CONSUMER PRODUCTS
DRILLING
SAMPLING
SHAFTING AND/OR TUNNELING
SELECTION OF OPERATING METHODS
DESIGN AND ENGINEERING
SHAFT SINKING AND TUNNELING
CLEARING AND GRUBBING
STRIPPING
UNDERGROUND AND SURFACE
CONSTRUCTION
BREAKING
LOADING
TRANSPORTING
UNLOADING
SIZE REDUCTION
SCREENING
CLASSIFYING
CONCENTRATING
DEWATERING
THERMAL DRYING
LEACHING

Figure 1. Scope of mining activities.

Source: Ref. 23.

Details specific to the activities addressed in this report are discussed in the following pages.

PREMINING ACTIVITIES (23,24)

Potential mine sites are evaluated to determine the presence of economical recoverable mineral deposits. This work, referred to as prospecting, usually includes ground and geochemical reconnaissance, examination of aerial photographs, and in certain special situations, sampling and drilling. Most modern prospecting activities leave the ground relatively undisturbed. After making an initial rough estimate of the general form and character of the expected ore body, the prospector or geologist submits his findings to those involved in the physical exploration and development.

The selection of an area for surveying may result from regional reconnaissance, a spot check of promising geologic situations described in published literature, submittal of site data by a prospector or independent geologist, or the decision to restudy an old mine or mining district. The area selected usually embraces ground beyond the site of actual interest. A total of less than 3000 hectares or as much as 30,000 hectares may be involved, depending on the type of mineral deposit being explored. When an area has been chosen, the site is prepared for the exploration team. This may involve activities such as constructing an access road, bringing in utilities (electricity and water), locating or developing housing for the exploration team, constructing helicopter pads, and establishing a communication system. Once preliminary site preparation is completed, exploration for a potential ore begins. The following is a list of some exploration methods and their definitions.

1) Geological method - A study of the geology of the ore deposit and its general setting. Involves geologic mapping and plotting by the use of various tools such as a transit, stadia, compass, and tape.

2) Geochemical method - A study of the chemistry of rocks, soils, waters, and the atmosphere.

3) Biochemical method - A study of plant material to determine trace metal content.

4) Geophysical method - A study of the physical characteristics of rocks and minerals. Six basic geophysical exploration methods are commonly employed in the search for minerals: gravity, seismic, magnetic, electromagnetic, electric, and radiometric.

At this stage a preliminary environmental assessment is undertaken to establish baseline conditions and to project potential impact from both exploration and possible later mining.

The physical work involved in the exploration methods defined usually includes trenching, pitting, and drilling. Trenching establishes the trend, width, and mineral character of an ore protruding from soil. This is normally accomplished with bulldozers and backhoes of various sizes, or sometimes mechanical or hydraulic rippers in rough ground. Drilling and blasting are rarely necessary because adequate samples are usually collected at the point where the rock becomes too hard to be moved by a ripper or blade. If irregular deposits are believed to extend beneath the soil cover or the alluvium is suspected to contain values such as placer gold, shallow pits (3 to 5 meters) are dug with small backhoes or circular shafts (in the range of 30 meters) are excavated with septic tank diggers. These machines can remove only the uppermost weathered bedrock. If penetration into the rock itself is required, shafting is usually done by pneumatic drilling and blasting with stick dynamite and standard fuse and blasting caps.

Other exploration techniques include overburden and exploration drilling. Overburden drilling is a shallow exploration method for obtaining small bedrock samples for geochemical analysis or in various geophysical interpretations. Exploration drilling, which is deeper, is used to study the ore itself. Percussion, rotary, and diamond drilling are the three most common methods used today. Equipment ranges in size and complexity from simple hand-operated augers to small-scale versions of oil-fired rigs.

Results of the exploration study are tabulated and used to locate and characterize (prove) the ore deposit. Data obtained from exploration studies may also be of value in planning extraction and hauling facilities, developing beneficiation operations, and establishing methods of waste handling and disposal.

After exploration has provided information on the shape and size of an ore deposit, its general geological characteristics, its average grade, etc., site development for mining begins. Mine development depends largely upon the kind of ore body and the mining method to be applied. Some common approaches to mine development are development drilling; access road construction; clearing and grubbing; adit or shaft development; overburden removal; establishment of utilities and communication; and construction of facilities such as the grinding mill, concentrating mill, and general office. The different types of equipment required range from small, simple units such as backhoes and dump trucks to sophisticated systems involving earth movers, draglines, and power shovels.

Although an effort is made to develop mine sites in harmony with the environment, some alteration and disturbance of the topography are unavoidable. An Environmental Impact Statement (EIS) or a Negative Declaration (ND) frequently is required at this stage of activities, depending on the significance of the Environmental Assessment (EA). This involves a detailed study of soil, water, air, vegetation, and wildlife in the vicinity of the site and the potential impacts of access roads and other developmental features, including socioeconomic impacts during and after the mine is closed down. Generally, premining activities are halted temporarily (for a year or more) while the study is conducted. Considerably more detail may be required if Federal land is involved, but in almost all cases an EA is a part of the premining operation and leads to a formal EIS when the impacts are significant or the project is controversial.

EXTRACTION PROCESSES

For purposes of this report, three specific mining categories are considered: underground mining, surface mining, and dredging. These extraction methods are described individually in this section, following the discussions on the various activities carried out simultaneously with ore extraction (drilling, blasting, and ore loading and transport).

Drilling, Blasting, and Ore Loading and Transport (25)

It is necessary to drill and blast to loosen portions of most mineral deposits before they can be removed, although some can be removed by power equipment such as front-end loaders, drag lines, and dredges.

Drilling consists of boring blast holes into the bedded minerals. The holes are subsequently charged with explosives and detonated. Tractor or truck-mounted pneumatic rotary or percussion drills are commonly used for this purpose. A rotary drill rotates a drill rod to which a bit (usually a roller-cone type) is attached and produces the borehole by the abrasive cutting action of the rotating bit. Percussion drills use compressed air to drive a piston that transmits a series of impacts or hammer blows, either through the drill rod, or, as in "down-the-hole" drilling, directly to the bit. The borehole is formed by the chipping and pulverizing action of the chisel-like bit impacting against the mineral surface. Normally, rotary drills are used in softer mineral deposits and percussion drills in harder deposits. The number, depth, spacing, and diameter of blast holes depend on the characteristics of the explosive used, the type of burden or mineral to be fragmented, and characteristics of the deposit such as the location of dips, joints, and seams.

Blasting is used to displace minerals from their deposits and to fragment them into sizes that require a minimum of secondary breakage and that can be readily handled by loading and hauling equipment. Once engineered, blasting practices consist simply of loading blast holes with a predetermined amount of explosives and stemming, then detonating them. Dynamites and blasting agents are the most commonly used explosives. Dynamites, which are highly explosive, come in a variety of types and grades, many of which contain nitroglycerine. Blasting agents are insensitive chemical mixtures of fuels and oxidizers. Mixtures of ammonium nitrate and fuel oil (ANFO) are the most common and consist of coated or uncoated fertilizer grade ammonium nitrate pellets, prills, or granules mixed with 4 to 6 percent fuel oil.

Blasting frequency ranges from several shots per day to one per week, depending on the plant capacity and the size of individual shots. The effectiveness of a shot depends on the characteristics of the explosive and the mineral.

The excavation and loading of broken minerals is normally performed by shovels and front-end loaders. At most surface mines, large haulage vehicles with a capacity of 18 to 68 megagrams are used to transport minerals from the mine to the primary crusher. At underground mines crude ore is transported to the surface in buckets or cars called "skips." Ore is transported to the skip by conveyors or haulage vehicles.

Underground Mining

An underground mine is a facility constructed to permit the extraction and removal of a mineral or metal ore from a natural deposit beneath the earth's surface. The mine also includes the area of land over which these extraction and removal activities occur or where these activities disturb the natural land surface. In some cases, the mine may also encompass areas affected by ancillary surface operations-haul roads or access roads, workings, impoundments, dams, ventilation shafts, drainage tunnels, entryways, refuse banks, dumps, stockpiles, overburden piles, spoil banks, culm banks, tailings, holes or depressions, repair areas, storage areas, and structures (23).

The choice of the underground mining method to be applied depends on a number of factors (23):

1. The assay (quality), size, and geometry of the ore deposit.

2. The amount and distribution of the minerals in that deposit.

3. The mechanical engineering, and chemical properties of the ore and the parent rock.

4. The economic situation of the mining operation.

5. Safety, health, and government regulations.

6. Special considerations (environmental impacts including socioeconomic, etc.).

Several methods are employed in underground extraction of mineral deposits, and descriptions of the more common ones follow.

Room-and-Pillar--

Room-and-pillar mining involves removal of an ore stratum with the exception of occasional columns or pillars; these pillars then provide support for the overlying rock strata. The method is commonly applied when ores are flat-lying or in gently dipping beds (Figure 2). The supports may be left in place or removed (or partially removed) for their mineral value. The structure of some areas requires that the pillars be left in place so that subsidence does not cause disturbance of original land surface. The pillars are left in place in a regular pattern while the rooms are mined out. If the pillars are to be removed, those farthest from the haulage exits are mined first, allowing the roof to cave in. Room-and-pillar mining is well-adapted to mechanization, and many different types of ore deposits are mined by this method.

Conveyors carry the ore mined in the rooms to the entry belt or mine car-loading station. Haulage in the rooms may be by conveyor, shuttle car, or load-tram unit. Elaborate water collection and pumping systems keep the mine dry during extraction of rooms and pillars.

Hydraulic Mining--

Another method of breaking minerals out of a solid body of rock is by hydraulic jets. This method can also provide immediate transportation of the materials, with the rate of removal dependent upon the material, the grade of the opening, and the water flow. If the material is highly flammable, such as the asphaltic mineral gilsonite, hydraulic mining is usually the preferred method of extraction. Although this method can be employed in either flat or vertical veins, additional water is required to flush out the mined material in a flat vein. Cutting can be accomplished with hand-held jets; however, jet cars, which are controlled either remotely or by an operator, or water cannons are more efficient. In vertical veins, the ore may be loosened by drilling before the jet cutting operation.

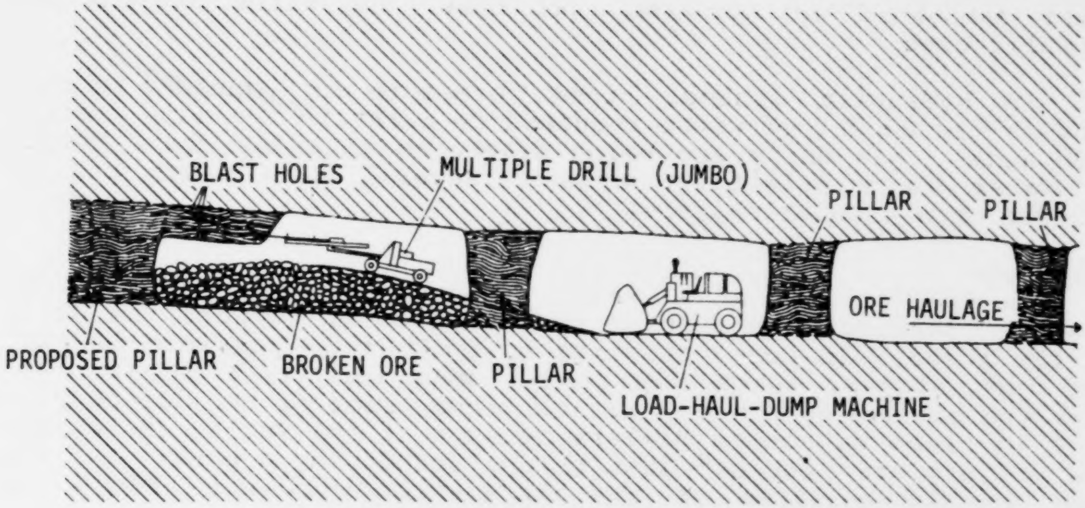

BLAST HOLES
MULTIPLE DRILL (JUMBO)
PILLAR
PILLAR
ORE HAULAGE
PROPOSED PILLAR
BROKEN ORE
PILLAR
LOAD-HAUL-DUMP MACHINE

Figure 2. Room-and-pillar mining method.

Source: Ref. 24.

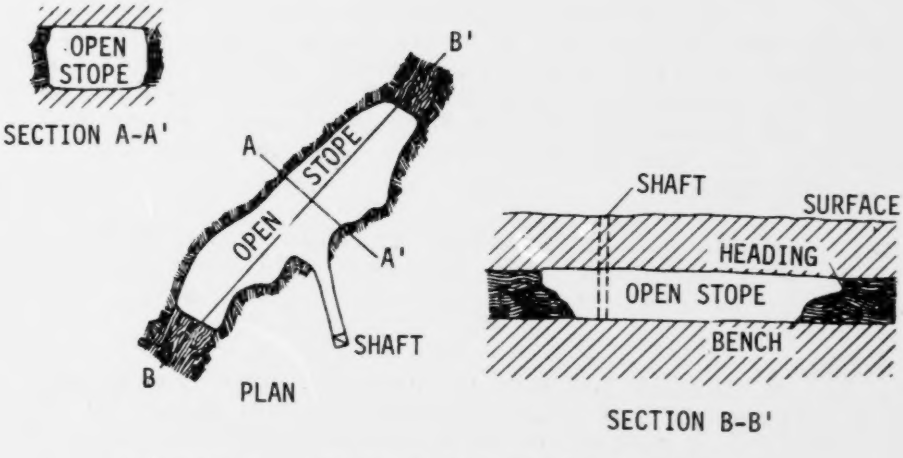

OPEN STOPE
SECTION A-A'
B'
A
OPEN STOPE
A'
SHAFT
B
PLAN
SHAFT
SURFACE
HEADING
OPEN STOPE
BENCH
SECTION B-B'

Figure 3. Open stope mining method.

Source: Ref. 24.

Whereas in level to moderately pitched veins the room-and-pillar method is the basic approach, for the more steeply pitched veins hand-held jet nozzles, jet cars, and water cannons are normally used.

In hydraulic mining, higher pressure through the nozzle lessens the amount of water required to maintain the same production rate. New Units are being developed that use short bursts of water in a pulsating action. Several such units can be mounted on a crawler chassis.

Stoping--

In open-stope mining, small ore bodies are mined out completely, leaving no pillar of ore in place to support the walls of the stope. In some varieties of rock it is possible to mine out huge stopes, which may remain open for years (Figure 3). When the ore being mined is of low grade, some of the ore body is left in place as random pillars to support the walls. Sometimes the pillars are "robbed" just before abandoning a portion of the mine so the collapse of the stope/walls will not affect the operation.

Sometimes narrow veins can be mined by the stoping method by placing an occasional wooden beam across from one end of the stope to another to support the vein walls. This is called stull stoping (Figure 4).

Shrinkage stoping (Figure 5) refers to stoping the ore deposit from beneath and allowing the broken ore to support the stope walls, a method mostly used in steeply dipping vein deposits where the walls and mineral body require little or no support. Space is left above the broken ore so that a miner can stand and drill overhead. The broken ore is drawn off as needed to maintain the headroom needed for drilling. After the stoping is completed, all the broken ore is removed and the walls are allowed to collapse.

Other variations of stoping include cut-and-fill stoping (used in wider, irregular ore bodies), rill stoping, hydraulic filling, and square-set stoping (24).

Block Caving--

The block caving method is used to mine large ore bodies over which barren or low-grade capping is too thick to strip away from the surface. Mining is accomplished by making a series of evenly spaced crosscuts below the bottom of the ore to be caved, from which raises are driven up to the ore. Then the entire ore body is undercut so that it will slowly cave into the raises (Figure 6). The weight of the ore provides enough force to break it up and move it downward, where it is drawn from beneath,

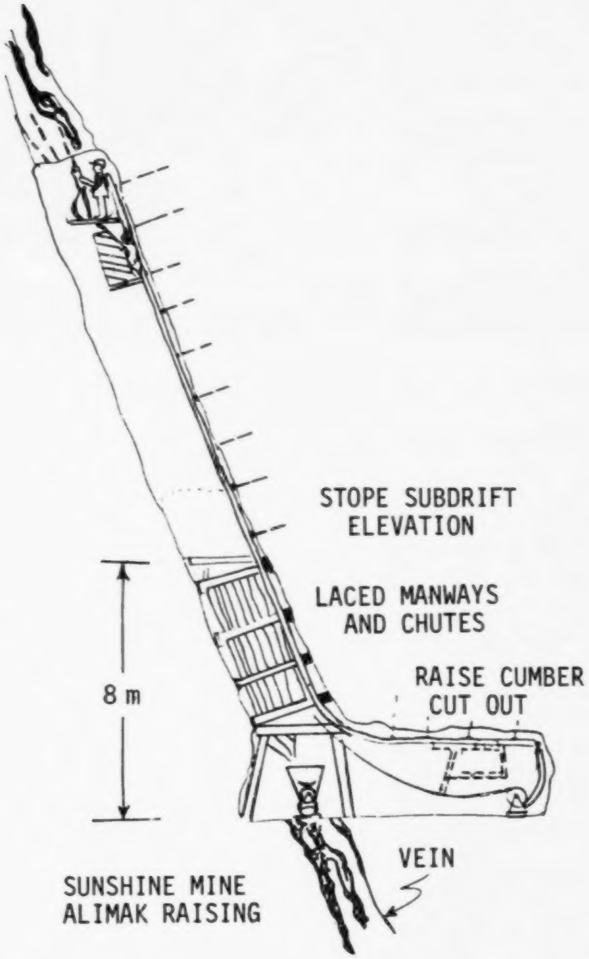

STOPE SUBDRIFT ELEVATION
LACED MANWAYS AND CHUTES
RAISE CUMBER CUT OUT
8 m
VEIN
SUNSHINE MINE ALIMAK RAISING

Figure 4. Stull stoping.

Source: Ref. 26.

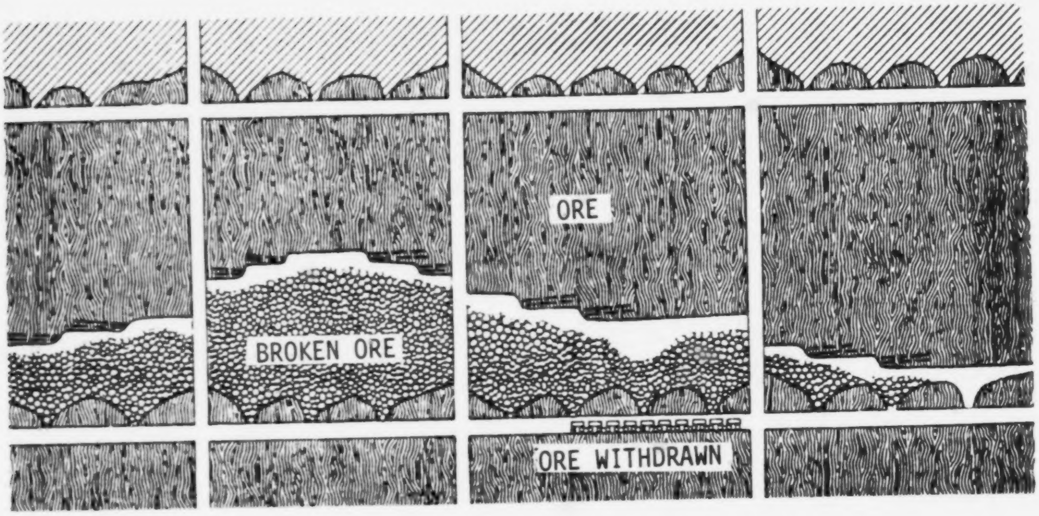

ORE
BROKEN ORE
ORE WITHDRAWN

Figure 5. Shrinkage stoping.

Source: Ref. 24.

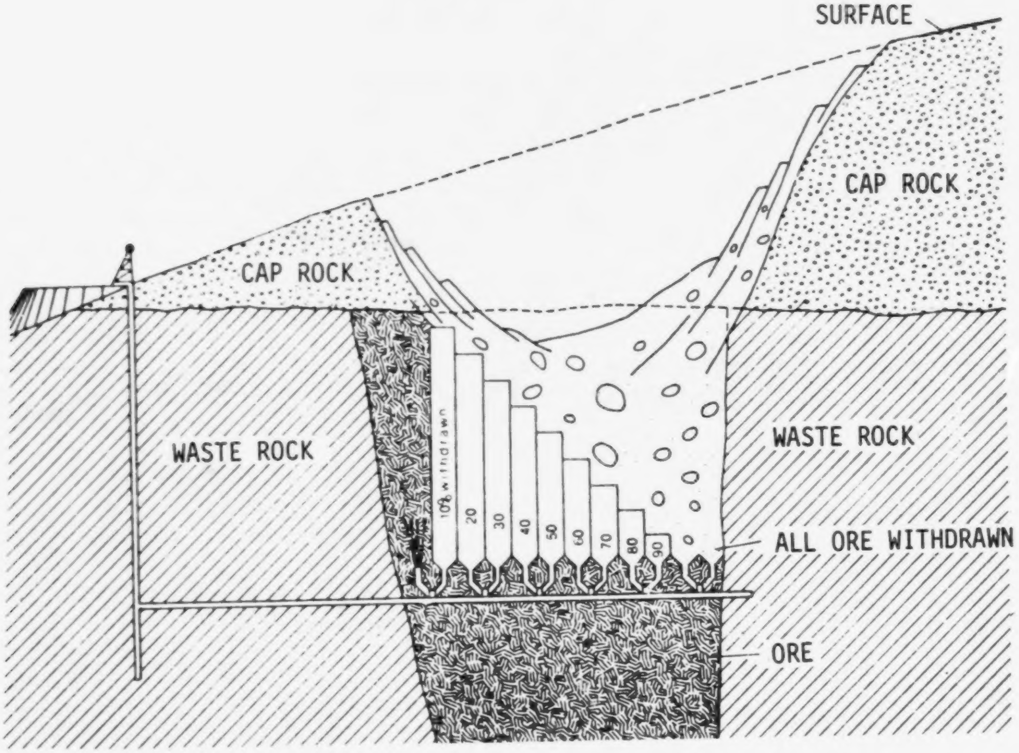

SURFACE
CAP ROCK
CAP ROCK
WASTE ROCK
WASTE ROCK
10% withdrawn
20
30
40
50
60
70
80
90
ALL ORE WITHDRAWN
ORE

Figure 6. Block caving underground.

Source: Ref. 24.

trammed to the shaft, and hoisted or hauled to the surface. As the broken ore is removed, the overburden will eventually descend until fragments of it come up from the raises, indicating that the ore body is mined out. This type of mining often leaves behind a surface depression because of the sinking overburden material. In mines containing pyrite and located in areas of sufficient precipitation to produce surface runoff, these depressions become a source of recharge for production of acid mine drainage, which must be collected, pumped, and treated during both mining and post-mining operations. Treatment of the acidic drainage is required for an indefinite (usually long) period of time.

Surface Mining

A surface mine is an open-air operation for extraction of metallic or nonmetallic minerals. Deposits recovered by this method may be in any rock type and are usually less than 150 meters deep, so that overburden removal is not prohibitively expensive (23). Minerals that are surface-mined are coal, copper, iron and aluminum ores; placer deposits of gold, tin, and platinum; and sand, gravel, stone, gypsum, and clays. Very large and efficient earth-moving machinery and auxiliary equipment recently developed make it possible to recover many ore deposits that could not be economically mined underground.

In general, a surface mine operation includes removing the overburden material covering the deposit, removing the mineral being recovered, and subsequently transporting the mineral to beneficiation processing operations. The following subsections cover specific types of surface mining.

Open-Pit Mines and Quarries--

Both of these surface mining methods involve open-air excavations. Open-pit mining refers to the extraction of metallic ores (Figure 7). Quarrying refers to the extraction of nonmetallic ores and construction materials.

Metallic minerals mined by open-pit methods include copper (porphyry) ores, iron ores (hematite and taconite), beryllium ore (bertrandite), mercury ore (cinnabar), aluminum (bauxite) ores, and to a lesser extent ores containing antimony, magnesium rare-earth metals, vanadium, and zinc. Nonmetallic minerals and construction materials that are quarried include sand and gravel, dimension stone, gypsum, clays, asphaltic materials, limestone, and asbestos.

The methodology of mineral extraction is essentially identical in open pits and quarries except that open pits normally are much deeper and require larger equipment.

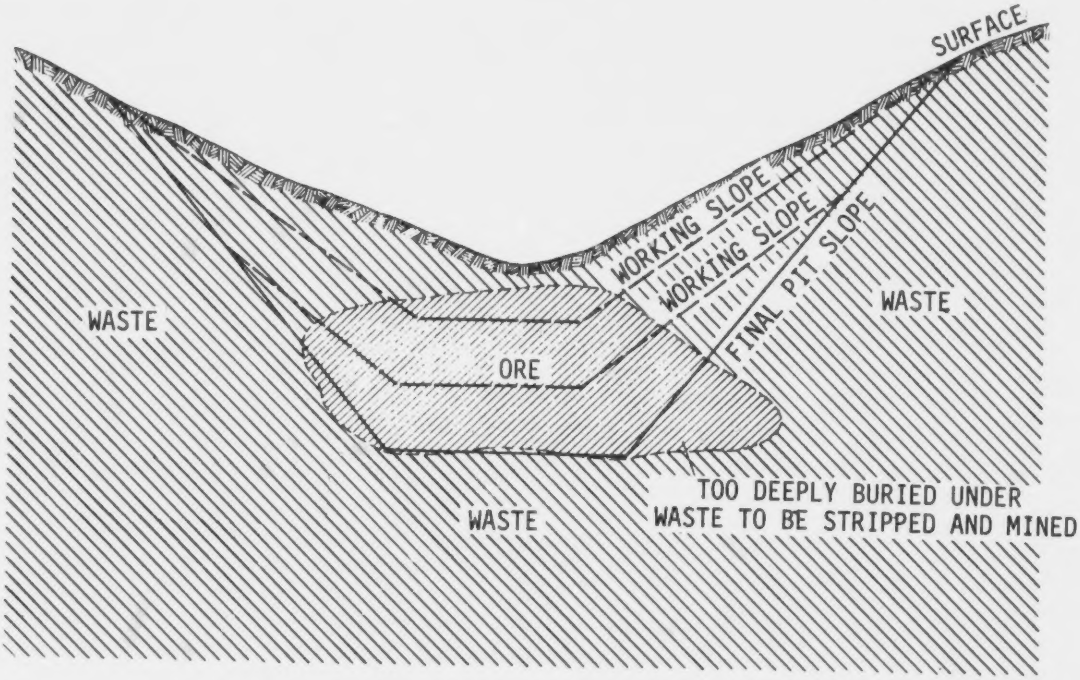

SURFACE
WORKING SLOPE
WORKING SLOPE
FINAL PIT SLOPE
WASTE
WASTE
ORE
TOO DEEPLY BURIED UNDER WASTE TO BE STRIPPED AND MINED
WASTE

Figure 7. Open-pit mining.

Source: Ref. 24.

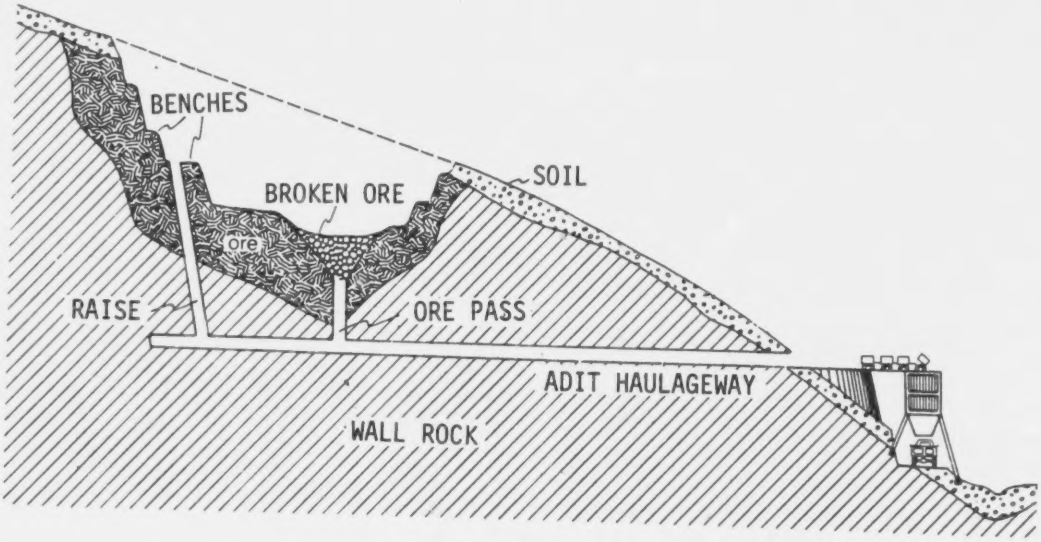

BENCHES
SOIL
BROKEN ORE
ore
RAISE
ORE PASS
ADIT HAULAGEWAY
WALL ROCK

Figure 8. Glory hole mining.

Source: Ref. 24.

Glory Holing--

A glory hole (Figure 8) is an open pit from which ore is excavated so that it falls by gravity into a raise (inclined or vertical shaft). The raise leads to an underground conveying system that transports the ore to the surface. This mining technique is applied to deposits that could also be mined by open-pit methods or to ore deposits that are narrow and nearly vertical. Both metallic and nonmetallic minerals can be recovered by glory holing.

Strip Mining--

In a strip mine, overburden is removed, frequently in great quantity, to expose a coal bed for extraction. Because coal mining is not included within the scope of this report, strip mining procedures are not discussed.

Placer Mining--

Placer mining involves the recovery of a placer deposit, which consists of alluvial or glacial minerals. Placer deposits are concentrations of heavy minerals in detrital (loosely packed) materials. The desired ores have been selectively settled in running water because of their high specific gravity. Gold, tin, platinum, diamonds, and various industrial metallic minerals such as zircon ($ZrSiO4$), ilmenite ($FeTiO3$), and rutile ($TiO2$) are recovered by placer mining techniques. No diamond deposits are worked in the United States. Industrial metallic minerals are recovered by dredging, a type of placer mining covered separately in this Section of the report.

Panning, suction dredging, sluicing, and "hydraulicking" are the primary placer mining methods for recovering gold, tin, and platinum deposits and other low concentration ores. These methods are described briefly.

Panning and sluicing--Panning, the legendary method of gold mining, involves filling a pan with creek or river-bottom gravel and swirling it in water with sufficient force to wash away the lighter detrital material and leave behind the heavier gold. Most surface deposits rich enough to be mined and concentrated by this method were exhausted long ago (24).

Sluicing is a method whereby ore and surrounding gravel are shoveled into an inclined sluice box; the heavy ore is trapped on small ridges along the water's path as the lighter gravel is washed on down the incline. Few unmined deposits remain in the United States where sluicing is economically feasible (24).

Hydraulic mining--The basic technique of surface "hydraulicking" is identical to hydraulic underground mining described earlier.

In surface hydraulic mining, the high-pressure water stream is directed against the base of the placer gravel bank to disintegrate the deposit. The broken material is washed to and through sluice boxes situated in convenient positions down slope. Many Western States have passed laws closely regulating hydraulic mining because it eventually disturbs a large surface area and land restoration is somewhat difficult (24).

Dredging

Dredging is a type of placer mining (a subcategory of surface mining) that involves the underwater extraction of minerals from placer deposits (alluvial or glacial deposits of sand and gravel containing particles of valuable minerals) (23). The deposits dredged are usually low-grade and lie near the surface. They are large in both a real extent and thickness. Minerals obtained by this method include placer deposits of gold, titanium, sand and gravel, and rare earths. (See Tables 3 and 4 for a complete listing.) Dredging operations may be conducted on public waterways (e.g. streams, lakes, rivers, estuaries) or in areas adjacent to public waterways that have been cleared, excavated, and flooded.

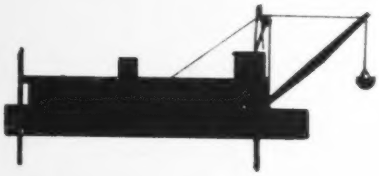
A classical dredge is basically a continuous digging machine that excavates large volumes of bottom deposits and transports them to the surface for beneficiation. Dredges can remove material from 3.7 to 30.5 meters below the surface of the water and have successfully removed material from a depth of 49 meters (23). Capacities of different types of dredges vary. Suction-type dredges, for example, are capable of extracting 272 to 454 megagrams of material per hour (27). Once the ore has been transported to the surface it can be partially or completely processed on board the dredge. At some operations, only initial waste/raw material separation takes place on board, and most of the beneficiation occurs at a land-based facility (25).

A variety of dredges are being used in the mineral mining industry. Factors that influence selection of the type and size of dredge include clay content of the deposit, particle size of the material being extracted, and the amount of water available to float the dredge. The two basic categories of dredges in use today are mechanical and hydraulic. Various types within these categories are illustrated in Figure 9 and described in the following paragraphs.

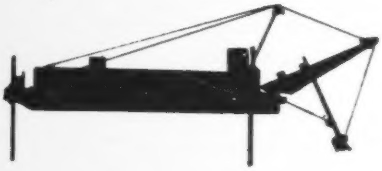
Mechanical Dredges--

Grapple dredge--This type of dredge consists of a clamshell bucket suspended from a derrick mounted on a barge. Clamshell dredges are most suitable for excavating medium-soft materials in confined areas near docks and breakwaters. Little waste material is discharged back into the body of water being dredged because

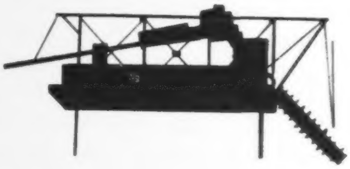
MECHANICAL



THE GRAPPLE DREDGE

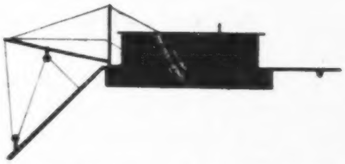


THE DIPPER DREDGE

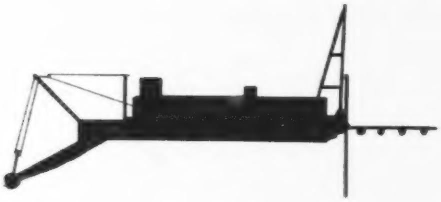


THE BUCKET DREDGE

HYDRAULIC



THE PLAIN SUCTION DREDGE



THE CUTTERHEAD PIPELINE DREDGE

Figure 9. Types of dredges used in excavation.

Source: Ref. 28.

all the raw material is transported on the barge to a land-based processing facility (27). Excess water and fines leave the barge while on the river.

Dipper dredge--This dredge has a powerful bucket mounted at the forward end, which gives the dipper its main advantage, a strong "crowding action" produced as the bucket is forced into material being moved (28). This dredge provides efficient removal of rock and other hard materials. The dipper's ability to handle larger rock reduces the need for blasting.

Bucket dredge--The bucket dredge, commonly referred to as the bucket-line or bucket-ladder dredge, consists of a series of buckets mounted on an endless closed-loop chain. Each bucket digs, conveys, and dumps its own load. This dredge is very efficient and operates at the lowest unit cost in mining placer deposits that principally lie below the water level. Minerals excavated by bucket-line dredges are usually processed on board. Tailings are discarded back to the water, and the product is loaded onto barges and hauled away.

Two principal types of bucket dredges are used. One has an inclined belt-conveyor stacker to discharge the coarse fraction of washed tailings well astern of the haul, and sluices to discharge the sand fraction a short distance astern. The other has only sluices for stern discharge of tailings. Bucket dredges are used for mining gold, tin, heavy industrial minerals (e.g., titanium, rare earths, zirconium), and sand and gravel (23).

Hydraulic Dredges--

Hydraulic dredges are designed for excavating materials lying under the water and transporting the solids in a pulp or slurry through a continuous system to a point of discharge (23). The pulp or slurry may be discharged into hoppers on board or into barges moored alongside or sent via a floating pipeline to a point ashore, to a treatment plant on board, or to one on a barge moored nearby. The hydraulic excavating system can be mounted on a barge, with or without propulsion, or on a self-propelled ship. It can be designed for operation in inland waters, protected coastal waters, or open seas. The two principal classifications of hydraulic dredges, based on method of imparting energy to the pulp, are pump dredges and air-jet or water-jet lift dredges. The dredges are additionally categorized by the manner in which material is dislodged and excavated from the bottom deposit: plain suction dredge and cutterhead dredge. The plain suction type consists of a suction pipe that is lowered to the surface of the deposit to be worked and a powerful pump that draws up the material mixed with water and discharges it through a pipeline (25). These units are used for digging soft deposits that contain no large boulders. The cutterhead dredge works on the same principle but is equipped with a powerful rotating cutter that loosens the material, which is then sucked through the dredging pump (25). These dredges are capable of digging all types of alluvial materials, as well as clay, hardpan, and other compacted deposits.

Portable suction dredges--Portable suction dredges are vacuum cleaner-like pipes or sluicera that operate on small floating rafts or barges anchored in a stream channel. The suction hose is operated on the river bottom by a scuba diver who selectively vacuums gold-laden sediments from the river bottom. The gold is separated on the raft by gravitational methods. Suction dredges are common on the streams of the northwestern United States.

BENEFICIATION

After ores are mined or dredged, they usually must be crushed, classified, concentrated and dried. Although all ores do not require such extensive beneficiation, a general flow diagram of the beneficiation process for nonferrous ores and construction materials is shown in Figure 10. Most of the processes shown are conducted at one site. Some size reduction takes place in blasting and mining the ore for transport, and in some underground operations primary crushing occurs below ground; however, for the most part beneficiation can be viewed as an operation usually composed of six major steps: size reduction, screening, classification, concentration, dewatering, and thermal drying. All beneficiation processes involve at least one of these major steps.

Most ores must first be reduced in size. In some underground mines size reduction is necessary before the ore can be transported to the surface. Size reduction (or comminution) of minerals is necessary either to separate desirable material from undesirable material (gangue) or to increase the surface area of the ore for further processing.

The four classifications within size reduction are primary crushing, secondary crushing, dry grinding, and wet grinding. A conventional pulverizing plant usually consists of one or more primary crushers, secondary crushers, and fine grinders.

Size reduction is initiated on run-of-mine ore in the primary crushing stage. The most common primary crusher in current use is the jaw crusher. Since primary crushers handle the largest particles, they must be capable of exerting the greatest force. The mechanical stress applied to a rock to strain it beyond its breaking point may be either compression or impact

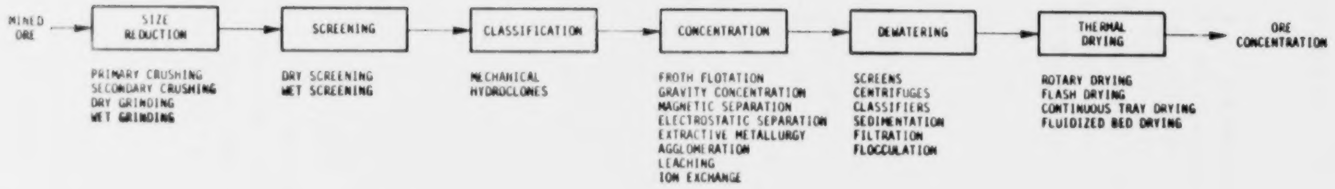

MINED ORE
SIZE REDUCTION
SCREENING
CLASSIFICATION
CONCENTRATION
DEWATERING
THERMAL DRYING
ORE CONCENTRATION
PRIMARY CRUSHING
SECONDARY CRUSHING
DRY GRINDING
WET GRINDING
DRY SCREENING
WET SCREENING
MECHANICAL
HYDROCLONES
FROTH FLOTATION
GRAVITY CONCENTRATION
MAGNETIC SEPARATION
ELECTROSTATIC SEPARATION
EXTRACTIVE METALLURGY
AGGLOMERATION
LEACHING
ION EXCHANGE
SCREENS
CENTRIFUGES
CLASSIFIERS
SEDIMENTATION
FILTRATION
FLOCCULATION
ROTARY DRYING
FLASH DRYING
CONTINUOUS TRAY DRYING
FLUIDIZED BED DRYING

Figure 10. Beneficiation processes.

Source: Ref. 23.

stress. These differ in the duration of time needed to apply the breaking force. In impacting, the breaking force is applied almost instantaneously, whereas in compression, the rock particle is slowly squeezed and forced to fracture. All crushers use both compression and impaction of various degrees. In primary crushing some reduction also occurs by attrition, the rubbing of stone on stone or metal surfaces. Crushers are usually loaded gradually between nonparallel crushing surfaces, except occasionally when impact breakers and roll crushers are used in the primary stage (23). Primary crushers are typically charged by means of a receiving hopper. At large mines, more than one hopper or dump bin may serve separate primary crushers placed in parallel. Depending on the ultimate size requirements of the product, the material from the primary crushers may be screened, with the undersize going directly to the screening plant and the oversize to secondary crushing, or all of the material may be routed to the secondary crushers.

Secondary crushers take all or a portion of the crushed material from the primary crushers and further reduce it. This may be the final comminution process or only an intermediate step. The term "secondary crushing" does not refer to the size of either the crusher or the crushed ore but only the sequence in which the crushing occurs. Generally, however, the average diameter of the feed is unlikely to exceed 12 centimeters, and the product usually has a top size range from 2.5 to 3.5 centimeters. Tonnage capacity of the secondary crusher need not match that of the primary unit; in most cases it is substantially less because screening is a common practice between the primary and secondary stages (23).

Grinding, which can be either wet or dry, reduces the ore to the optimum size for further treatment. Unlike the equipment used in primary and secondary crushing, grinders do not reduce product to a maximum size, a sizing apparatus such as a mechanical classifier or a cyclone must be used to limit the maximum size of the discharge. Oversized particles are then recycled through the grinder. Creation of a wet pulp or suspension in a ball, rod, or pebble mill operation has definite advantages when concentrating or extractive steps are conducted in the same environment as the grinding. It aids the longitudinal flow through the mill, has a cushioning effect on the tumbling bodies in the grinding, controls dust, and facilitates the addition of chemical reagents for futher processing (23).

Solids are usually separated according to size to obtain maximum production from the crushing and grinding equipment. Commercial crushing and grinding always produces a distribution of sizes, irrespective of the characteristics of the feed. This characteristic of the crushing and grinding units requires that screening and classification be used in almost all beneficiation processes.

The several screening devices available are classified as stationary, mechanical, high-speed mechanical, and electrically vibrated. The trend is from stationary grizzles to vibrating, multideck, mechanical screens on which deck motions can be straight-line, circular, or elliptical. High speed mechanical screens are widely used for separations of 4-mesh and finer. Electrically vibrated machines are used for separations of 8-mesh and finer (29).

Wet screening is used extensively for mineral processing. Using a wet slurry can increase the amount of material that is made to pass through a unit area of screen surface. Depending on the size of the screened particle, this capacity can be increased by from 25 to 350 percent (29).

Mechanical classifiers or cyclones frequently are used for size separation of fine particulate matter. Water is the suspending medium with mechanical classifiers, and either water or air with cyclones. With both types of units, the separation size is based on the relative velocity with which a particle moves through the suspending medium.

Mechanical classifiers consist primarily of rake or spiral types. Larger particles settle out in a settling tank and are then removed by either a mechanical rake or a spiral.

As a sizing device, the hydroclone generally is preferred over the mechanical classifier because it takes less floor space and costs less. The hydroclone usually operates at pressures exceeding 34.5 kilo pascals and converts this energy into rotational fluid-solid motion. Consequently, particles are separated according to their mass. The centrifugal force acting on the particles in a hydroclone is much greater than the normal gravitational force responsible for sedimentation in the mechanical classifier (29).

Concentration is used primarily in the beneficiation of nonferrous metals rather than construction materials. Deposits normally consist of mixtures of various minerals. To become usable these minerals must be separated from the unwanted gangue. Various concentration methods for this purpose include flotation, gravity concentration, magnetic separation, electrostatic separation, extractive metallurgy (pyrometallurgy, hydrometallurgy, electrometallurgy), and agglomeration.

Froth flotation is used most widely to beneficiate complex and low-grade ores. Flotation is a complex physicochemical process that takes place in an ore pulped with water, by which the surfaces of one or more minerals in the pulp are made water-repellent and the minerals attach themselves to air bubbles. When the mineral-laden bubbles (froth) rise to the surface they are skimmed off and sent to further concentration steps. Collectors are used to selectively coat the surfaces of the minerals to be floated with a water-repellent surface. Activators, pH controllers, depressants, and dispersants are used to make the collectors selective under a given set of physical conditions. By changing any of these conditions (such as pH) a sequential series of flotations may be obtained from a given pulp. Frothers are also used to keep the air bubbles intact so that the floated minerals will remain on the surface for removal (23).

Gravity concentration separates solids of different specific gravities in a fluid medium, usually water or air, but sometimes a heavy medium is used. Mineral mixtures susceptible to separation by gravity methods are those in which valuable minerals and gangue differ appreciably in specific gravity. For simple methods, a specific gravity differential of at least 1.5 is desirable. Methods of gravity concentration include the simple sluice, pinched sluice, Humphrey's spiral, sink-float mechanism, jig, shaking table, and various dry concentration methods (23).

Magnetic separation sorts one solid from another by means of a magnetic field. This method is based on the principle that particles placed in a magnetic field are either attracted or repelled by it. The only important highly magnetic mineral is magnetite. Many other minerals are measurably susceptible to magnetic action but fewer than 20 are amenable to magnetic separation, and these are classed as weakly magnetic. Magnets are also used to remove tramp iron from an ore feed (23).

Electrostatic separation of mineral grains is an integral part of the treatment of beach sands. Dry particles subjected to a surface electrical charge, on or before entering an electrostatic field, behave in accordance with their ability to conduct electricity. Conductive particles are repelled by the active electrode emitting the charge. Different minerals become charged to different degrees and are separated on this basis. Electrostatic separation is used to recover ilmenite, rutile, and zircon from beach sands and to remove feldspar and mica from quartz (23).

Extractive metallurgy is used to alter chemically the mineral constituents of an ore to facilitate their separation from the gangue. The three categories of extractive metallurgy are pyrometallurgy, hydrometallurgy, and electrometallurgy. Pyrometallurgy involves operations that use refractory furnaces and high temperatures created by electrical energy or by burning fuels to produce refined metals from ores and concentrates. The major processes include drying, roasting, sintering, distilling, smelting, and fire refining (23). These techniques are generally considered final metal refining processes rather than part of beneficiation. The electrometallurgy process uses electric current to recover metals. The two basic types of electrometallurgy are categorized on the basis of depending on how the electric current is used. If it is used as a source of heat, the process is referred to as electrothermic. If the electric current is used to transport metal ions from anodes and/or electrolytes for deposition on cathodes, it is referred to as electrolytic processing (23). Electrometallurgy, like pyrometallurgy, is considered more a final purification operation than a beneficiation process.

The final extractive metallurgical operation to be considered is hydrometallurgy, which involves the recovery of metals from ore and concentrates by selective dissolution. The processes involved in hydrometallurgy include preparation of the feed, leaching, separation of the metal-bearing solution from the leach residue, and purification of the solution following metal recovery (23). Leaching, which is considered a beneficiation process, is the main process of concern in this report.

Leaching refers to dissolving away of gangue or metal values in aqueous acids or bases, liquid metals, or other special solutions (29). The leaching solutions may be either strong general solvents (e.g. sulfuric acid) or weaker specific solvents (e.g. calcium). The specific solvents will attack only one or a few ore constituents whereas the general ones will attack a number of constituents. The action of solvents can be enhanced by heating, agitating, or applying pressure. Leaching can be accomplished by a variety of techniques. In-vat leaching takes place in a container, which may or may not be equipped for heating, agitating, or pressurizing. Leaching that takes place in the ore body is referred to as in situ leaching. The solvent is introduced into the ore body by pumping or percolation through overburden. Heap or dump leaching involves the leaching of stored tailings or ore on a surface that has been lined with an impervious material (clay or plastic sheeting). In this technique the solvent is sprinkled over the heap and the leached material is collected in furrows or troughs. Metals covered in this report that require some recovery by leaching are gold, copper, mercury, and silver.

The final concentration process considered here is agglomeration. Agglomeration forms masses or clusters from fine particles. The four main agglomeration processes are sintering, pelletizing, briquetting, and modulizing. As with chemical beneficiation, most agglomeration processes are a part of refining rather than beneficiation (23). Agglomeration is also used in a different sense to describe thickening of flotation tailings by use of agglomerating agents such as polyelectrolytes.

If wet screening, classification, or concentration techniques are used or if the moisture content is high in the initial ore (as dredged material), dewatering must precede the drying process. Mechanical dewatering removes water by means of gravity and centrifugal forces. Thickeners also are used to increase the concentration of solids in a slurry, whereas clarifiers are used to remove solids from a slurry. Mechanical dewatering is accomplished with screens, centrifuges, and classifiers, and by sedimentation, filtration, and flocculation (23).

When concentrates are dried commercially, heat is transferred by convection by direct contact between the wet solid and hot air. The various types of thermal dryers include rotary, flash, continuous-tray, and fluidized-bed dryers. After drying, the mineral is generally stored for shipment (23).

As mentioned previously, not all beneficiation techniques for mineral ores containing nonferrous metals and construction materials require all of the processes outlined. Many construction materials require only size reduction, screening, and drying; whereas many nonferrous metals require extensive concentration steps. It is only necessary, however, to delete those steps from the generalized flow chart that are unnecessary for a specific mineral.

SECTION 3

GENERAL WASTE CHARACTERISTICS AND CONTROL

Many different types of pollution problems arise from the large volume of construction materials and nonferrous metals mined and beneficiated in the United States. Pollutants include fugitive particulates from drilling and blasting, spent process water from concentrating operations, and gangue and overburden generated as a result of ore extraction. Some of the pollutants may be contaminated with materials considered potentially hazardous. For example, fugitive emissions may contain asbestos fibers or free silica particles, and some process wastewater may contain various heavy metals and/or toxic reagents like cyanide. In most cases the potential environmental effects of mining can be maintained at acceptable levels by the application of established waste management practices.

This chapter describes the sources and characteristics of air, liquid, and solid waste and the treatment and control technology typically used in the mineral mining industry to abate waste problems. Since the characteristics of liquid wastes from mining of construction materials and nonferrous metals are different, they are discussed separately.

AIR EMISSIONS AND CONTROL TECHNOLOGY

Emissions

Air pollution emissions in the mineral mining industry consist primarily of particulates from various phases of the mining process and from on-site beneficiation processes. Emission sources are categorized as fugitive or point sources. Table 6 lists the operations included within each category. Fugitive emissions, for the purpose of this report, are defined as ... "Particulate matter which escapes from a defined process flow stream due to leakage, materials charging/handling, inadequate operational control, lack of reasonably available control technology, transfer of storage" (25). Process point emissions are those emitted from a definable point, such as a stack.

Factors Affecting Fugitive and Process Emissions--

Emissions common to most mining and beneficiation operations are affected by the moisture content of the ore, the type of ore, the amount processed, the type of equipment, operating practices and a variety of geographical and seasonal factors. These factors, discussed in more detail below, apply to both fugitive and process sources and usually combine to determine the total emission problem of a facility.

TABLE 6. FUGITIVE AND PROCESS POINT EMISSION SOURCES

Fugitive sources	Process point sources
Drilling	Crushing and grinding
Blasting	Screening
Loading and hauling	Conveying
Stock and waste piles	Drying
Overburden removal[a]	
Mine roads	
Wind erosion of unprotected surfaces[a]	
Land reclamation	

[a] Applicable only to surface mines.

The inherent moisture content of the ore processed has a substantial impact on total uncontrolled emissions especially during mining, material handling, and initial plant process operations such as primary crushing. Surface wetness causes fine particles to agglomerate or to adhere to larger particles with a concomitant dust suppression effect. As new fine particles are created by crushing and attrition and moisture content is reduced by evaporation, this suppressive effect diminishes and may even disappear.

The type of ore processed is also significant. Soft ores produce a higher percentage of screenings than hard minerals because of a greater tendency to crumble and a lower resistance to fracture. Thus, the processing of soft rocks produces a greater potential for emissions than the processing of hard rock. The type of ore also governs the hazardous constituents contained in particulate emissions. For example, particulates from some talc and sand and gravel processing are known to contain asbestos and free silica, respectively.

Equipment types and operating practices also affect uncontrolled emissions. Equipment selection is based on parameters such as quarry characteristics, minerals processed, and desired end products. Emissions from process equipment such as crushers, screens, and conveyors, are generally a function of the amount of material processed, its size distribution, and the amount of mechanically induced velocity applied. The crushing mechanism (compression or impact) of the crushers also affects emissions.

Climate is the most significant geographical factor affecting uncontrolled particulate emissions. The wind velocity, wind direction, amount and intensity of precipitation, and relative humidity can affect emissions significantly, especially fugitive emissions. For example, the level of emissions can be expected to be greater in arid regions than in temperate ones. Other geographical elements that affect fugitive emissions include the topography and the extent and type of vegetation around a facility.

Seasonal changes affect emissions in several ways. For instance, the lower moisture content of the ore and high evaporation rate during the summer months cause uncontrolled emissions to be higher than at other times of the year. Shutdown of many operations during the winter months also affects total annual emissions.

Fugitive Emissions--

Fugitive dust constitutes a large portion of the emission problem in the nonmetallic mineral industry. Drilling, blasting, loading, hauling, dumping, storage piles, waste piles, overburden removal, wind erosion of unprotected surfaces, and land reclamation activities all contribute fugitive dust.

Particulate emissions from drilling operations are caused primarily by air flushing the bottom of the hole to remove cuttings and dust. Compressed air is released down the hollow drill center, forcing cuttings and dust up and out the annular space formed between the hole wall and drill.

Emissions from blasting are inherently unavoidable. Factors affecting emissions include the size of the shot, blasting procedures, rock type, and meteorological conditions, especially wind.

Considerable fugitive dust emissions may result from loading and hauling operations. Emissions emanate from load gathering, loading operations, vehicular transport over the unpaved roads associated with mining operations, and air motion across the load during hauling. The most significant factor affecting emissions during loading is the wetness of the ore. Factors affecting emissions from hauling operations are type of road surface, wetness of the surface, and volume and speed of vehicle traffic.

Truck dumping generates dust as the material tumbles from the truck bed and strikes the ground or the side of the receiving hopper. Dust emissions may also occur at the edge of a spoils slope when a truck dumps waste material or overburden. This simple operation has been identified as a significant fugitive dust source (30, 31).

Fugitive dust emissions from the storage area occur as a result of several activities, which include, in order of decreasing significance, equipment and vehicle movement in the storage area, wind erosion, loadout from the storage piles, and loading onto the storage piles. The emissions from waste and tailings piles are similar in mineralized identity to those from primary storage piles, but because the particles are finer they travel further.

Fugitive emissions associated with reclamation operations result from wind erosion of unvegetated or partially vegetated land. These emissions are related to wind speed, surface texture, and degree of vegetation cover (if any).

Emission factors for various phases of mining and process operations are presented in subsequent sections of this report covering individual minerals.

Process Emissions--

Although emissions from process point sources are significant, they are easily controlled because the processes are primarily stationary and the emissions emanate from a defined point. Sources include crushing, grinding, screening, conveying, and drying.

Generation of particulate emissions is inherent in the crushing process. Emissions are most apparent at crusher or grinder feed and discharge points. Factors that influence emissions include the moisture content of the rock, the type of rock processed, and the type of crusher used.

The most important element affecting emissions from crushing and grinding equipment is whether the reduction mechanism is compression or impact. This has a substantial effect on the size reduction achieved, the particle size distribution of the product (especially the proportion of fines produced), and the amount of mechanically induced energy imparted to these fines.

Dust emitted from screening operations results from agitation of dry rock particles. The level of uncontrolled emissions is dependent on the particle size of the material screened, the amount of mechanically induced energy transmitted, and other factors discussed earlier.

Generally, screening of fines produces higher emissions than screening of coarse sizes. Also, screens agitated at large amplitudes and high frequencies emit more dust than those operated at lesser amplitudes and frequencies.

Particulate emissions can occur in all material handling and transfer operations. As with screening, the level of uncontrolled emissions depends on the size of the material and how much it is agitated. The most emissions probably occur at conveyor belt transfer points where material is discharged from the conveyor at the head pulley or received at the tail pulley. The conveyor belt speed and the free-fall distance between transfer points affect the volume of emissions from these sources.

Emission Control Technology

The diverse particulate emission sources in mining and processing operations have resulted in the application of a variety of control methods and techniques. Dust suppression techniques for preventing particulate matter from becoming airborne are used to control both fugitive and process dust sources. Collection systems are used to control particulate emissions that can be contained and captured.

Control of Fugitive Dust Sources--

Almost all fugitive dust controls involve one (or a combination) of three basic techniques: watering, chemical stabilization, and reduction of surface wind speed across exposed surfaces. Watering costs the least but also provides the least permanent dust control. Depending on the source of the dust, water may effectively suppress the dust for only a few hours or for several days. A film of moisture creates a direct cohesive force that holds surface particles together; it also forms a thin surface crust that is more compact and mechanically stable than the material below and therefore less subject to producing dust after drying. Since this crust and its dust-reducing capability are easily destroyed by movement over the surface or by abrasion from loose particles blown across the surface, repeated watering is required to maintain the moisture film or surface crust.

Several types of chemicals are effective fugitive dust reducers. These are applied directly to the surface of the dust source. Some of the materials can "heal" (re-encrust) if the treated surface is disturbed, but many will not reform a crust. The effect of natural weathering on the life of the treated surface also varies widely with different chemicals. The primary use of chemical stabilizers in the mining industry is for land reclamation after the mining potential of an area has been exhausted; however, chemicals may also be applied to piles of overburden, waste, and tailings.

Air movement, or wind, contributes significantly to the incidence of fugitive dust from all sources, thus the reduction of wind speed across the source is a means of reducing emissions. Construction of windbreaks and enclosures or coverings for the sources, and the planting of grasses or grains on or adjacent to the exposed surfaces are some methods of reducing wind speed. If vegetative techniques are applied, the soil must provide nutrients moisture, and proper texture, and must be free of materials toxic to plant life.

The following paragraphs discuss in more detail how one or more of the foregoing techniques control fugitive dust.

Control of drilling operations--The two methods generally available for controlling particulate emissions from drilling operations are water injection and aspiration to a control device.

Water injection is a wet drilling technique in which water or water plus a wetting agent or surfactant is injected into the compressed air stream used for flushing the drill cuttings from the hole. The injection of the fluid into the airstream produces a mist that dampens the ore particles and causes them to agglomerate. As the particles are blown from the hole, they drop at the drill collar as damp pellets rather than becoming airborne. The addition of a wetting agent increases the wetting ability of water by reducing its surface tension (32).

Dry collection systems also may be used to control emissions from the drilling process. A shroud or hood encloses the drill rod at the hole collar. Emissions are captured under vacuum and vented through a flexible duct to a control device for collection. The most commonly used are cyclones or fabric filters preceded by a settling chamber. In this application collection efficiencies of cyclone collectors are usually not high. They are more suitable for coarse-to-medium-sized particles than for fine particulates. Fabric filter collectors, on the other hand, exhibit collection efficiencies in excess of 99 percent.

Control of blasting operations--No effective methods are currently available for controlling particulate emissions from blasting. Good blasting practices, however, can minimize noise, vibration, air shock, and dust emissions. Multidelay detonation devices that detonate the explosive charges in millisecond time intervals may reduce these adverse effects. Scheduling of blasting operations to coincide with such favorable meteorological conditions as low wind speed and low inversion potential can substantially reduce the impact of emissions from blasting.

Control of loading operations--The loading of dry raw materials generates fugitive dust emissions regardless of the method. Limited control may be attained by wetting the materials before loading. Water trucks equipped with hoses or movable watering systems may be used.

Control of hauling operations--The hauling of raw materials from the mine or quarry to the processing plant is responsible for a large portion of the fugitive dust generated by the industry. Temporary haul roads are built to accommodate advancing quarry faces, and they are usually unimproved. The movement of large, rubber-tired vehicles over these roads is a major source of dust. The amount of these emissions relates directly to the condition of the road surface and the volume and speed of vehicle traffic. Consequently, control measures involve improving road surfaces, supressing dust, and changing operations to minimize the effect of vehicle traffic.

Various road treatment methods to control fugitive emissions from haulage roads include watering, surface treatment with chemical dust suppressants, soil stabilization, and paving. Watering is the most common. Water is sprayed onto the road by water trucks equipped with either gravity spray bars or pressure sprays. The amount of water required, frequency of application, and effectiveness depend on weather elements, road bed condition and the willingness of the operator to allocate the necessary resources to do an effective job.

Road dust can also be suppressed by periodically applying wet or dry surface-treatment chemicals. Oiling is the most common surface treatment. The frequency of application may range from once a week to only several times a season, depending on weather conditions. A potential adverse environmental impact of this treatment is the floating away of the oil into streams or percolation into aquifers. Oiling is sometimes supplemented by watering; however, care must be exercised with this approach since improper application can cause slippery, dangerous road conditions.

Other treatments include the application of hygroscopic chemicals (substances that absorb moisture from the air) such as organic sulfonates and calcium chloride. When spread directly over unpaved road surfaces, these chemicals dissolve in the moisture they absorb and form a clear liquid that is resistant to evaporation. Consequently, these chemicals are most effective in areas with relatively high humidity. Since the chemicals are water soluble, repeated application may be required in areas with frequent rainfall. Also these agents can contribute to corrosion of expensive haulage vehicles.

Other alternatives include the following:

1. Soil stabilizers--These agents, which usually consist of a water-dilutable emulsion of either synthetic or petroleum resins and act as an adhesive or binder, are applied once daily to the road surface. In addition to being environmentally beneficial, these stabilizers offer considerable savings and operating benefits over traditional watering methods. Operators report reduced labor costs, lower maintenance costs on haulage vehicles, and safer road conditions.

2. Paving--Although it is probably the most effective means of reducing particulate emissions, paving entails high initial cost and requires subsequent maintenance and repair of damage caused by heavy vehicle traffic.

3. Control of traffic speed and reduction of volume--Replacing smaller haulage vehicles with units of larger capacity would reduce the number of trips required and the total emissions per ton of rock hauled. A stringent program to control traffic speed also would reduce dust emissions. According to a study on emissions from conventional vehicle traffic on unpaved roads, reducing the average speed from 48 kilometers per hour (for which an emission level of 1.0 kilogram per vehicle kilometer was established) to 40, 32, and 24 kilometers per hour resulted in emission reductions of 25, 33, and 40 percent, respectively (33). Although the situations may not be completely analogous, it can be concluded that an enforced speed limit of 8 to 16 kilometers per hour would substantially reduce fugitive dust emissions from quarry vehicle traffic and provide the additional benefits of increased safety and longer vehicle life.

4. Wind breaks--Planting of rapidly growing hedges or construction of temporary wooden walls upwind of major dust sources can reduce emissions by limiting the movement of air across the dust-laden surfaces.

Control of aggregate storage piles--Aggregate stockpiles are a significant source of fugitive dust. Emissions occur during creation of stockpiles and from wind erosion of formed piles. During the construction of stockpiles by stacking conveyors, particulate emissions are generated by wind blowing across a stream of falling material and causing the segregation of fine from coarse particles, and from the impact of falling aggregate on the pile. Control methods include wet dust suppression and devices designed to minimize the free-fall distance and thus reduce both exposure to wind and force of impact.

Control devices include stone ladders, telescoping chutes, and hinged-boom stacker conveyors. A stone ladder consists simply of a section of vertical pipe into which material from the stacking conveyor is discharged. The pipe has square or rectangular openings at different levels through which the material may flow. In the telescoping chute, material is discharged to a retractable chute and falls freely to the top of the pile. As the height of the stockpile increases or decreases, the chute is gradually raised or lowered accordingly. A similar device, the stacker conveyor, is equipped with an adjustable hinged boom to raise or lower the conveyor according to the height of the stockpile.

An alternative is to install water sprays at the stacking conveyor discharge pulley to wet the product. A pug mill can be used to eliminate particulate emissions from very fine products like stone sand by mixing the product with water before stockpiling. Finely ground material that cannot be wetted should be stored in silos until shipped.

Application of water is the technique most commonly used for controlling windblown emissions from active stockpiles. A water truck equipped with a hose or other spray device applies the water.

The location of stockpiles behind natural or manufactured wind breaks helps to reduce windblown dust. Also, active piles should be worked from the leeward side. Even though they may create load-out problems, stockpile enclosures or silos are the only effective controls for very fine materials or materials that must be stored dry.

Control of yard and other open areas--Fugitive dust emissions from plant yard areas are generated by vehicle traffic and wind. Generally, simply maintaining good housekeeping practices will control emissions from these areas. Spillage and other potential dust sources should be cleaned up. Brush-type or vacuum-type street sweeping is effective on paved or other smooth yard surfaces. Treating with soil stabilizers and planting vegetation are viable control options for large open areas and overburden piles. Many chemical stabilizers on the market provide some aid to the emergence and growth of vegetation and offer effective control against rain and wind erosion (34).

The application of soil stabilizers made of petroleum or synthetic resins in emulsion is moderately effective for storage piles that are inactive for long periods of time and for permanent waste piles or spoil banks. These chemical binders cause the topmost particles to adhere to one another to form a durable surface crust that resists wind and rain erosion as long as the surface crust remains intact. However, wind errosion and freezing and thawing can break up the surface.

Control of conveying operations--Conveying operations may produce fugitive dust emissions in addition to the emissions generated at transfer points. These emissions may be either mechanically induced or windblown.

Control methods include dust suppression and covering. Covering open conveyors is the most effective way to provide protection from wind and prevent particles from becoming airborne. Covered conveyors also yield certain operating benefits. For example, during inclement weather the covers reduce potential mud cake buildup on belts that can result in damage to conveyors, hazardous operating conditions, screen blinding, and the production of products that do not meet specifications because of retention of fines.

Control of Particulates from Process Operations--

Operations at a typical nonmetallic mineral processing plant generates dust at many points, including the crushers, grinders, screens, conveyor transfer points, and storage facilities. Consequently, effective emission control is complex and difficult. Control methods include wet dust suppression, dry collection, and a combination of the two. In wet dust suppression, moisture is introduced into the material flow, causing fine particulate matter to remain with the material flow rather than become airborne. Dry collection involves hooding and enclosing dustproducing points and exhausting emissions to a collection device. Combination systems apply both methods at different stages throughout the processing plant. Housing process equipment in enclosed structures is another effective means of preventing atmospheric emissions. Such buildings generally must be vented through a control device.

Wet dust suppression--Wet dust suppression systems control dust emissions by spraying moisture in the form of water or water plus a wetting agent at critical dust-producing points in the process flow, causing dust particles to adhere to larger mineral pieces or to form agglomerates too heavy to become or remain airborne. Thus, the objective of wet dust suppression is not to capture and remove particulates emitted from a source, but rather to prevent their emission by moist agglomeration at all process stages.

Water sprays are not practical in all cases because moisture may interfere with further processing such as screening or grinding, where agglomeration cannot be tolerated. Also the capacity of the dryers used in some of the processing steps limits the amount of water that can be sprayed onto the raw materials. Since water cannot be added after the materials have passed through the drying operations, other means of dust control must be applied then.

The unusually high surface tension (72.75 dynes per square centimeter at 20°C) requires that 5 to 8 percent moisture (by weight), or greater, be added to adequately suppress dust (35). In many installations this is not acceptable because excess moisture can cause screening surfaces to blind, which reduces both capacity and effectiveness, or can cause the coating of mineral surfaces, which yields a marginal product or unacceptable product. To counteract these deficiencies, small quantities of specially formulated wetting agents or surfactants are blended with the water to reduce surface tension and improve wetting efficiency, thereby minimizing the moisture necessary to suppress dust particles. Although composition of these agents may vary, their molecules are characteristically composed of two groups, a hydrophobic group (usually a long-chain hydrocarbon) and a hydrophilic group (usually a sulfate, sulfonate, hydroxide, or ethylene oxide). When introduced into water, these agents reduce its surface tension appreciably (to as low as 27 dynes per square centimeter) (36).

One or more spray headers fitted with pressure spray nozzles distribute the dust suppressant mixture at each treatment point at the rate and in the configuration required to effect dust control. Spray actuation and control are important to prevent waste and undesirable muddiness, especially during intermittent material flow. Spray headers at each application point normally are equipped with an on-off controller interlocked with a sensing mechanism, allowing sprays to operate only when material is flowing.

Dry collection systems--Particulate emissions generated at plant process facilities (crushers, screens, conveyor transfer points and bins) are controlled by capturing and exhausting the emissions to a collection device. Depending on the physical layout of the plant, emission sources are manifolded to one centrally located collector or to a number of strategically placed units. Dry collection systems consist of an exhaust system with hoods and enclosures to confine and capture emissions and ducting and fans to convey the captured emissions to a collection device for particulate removal before the airstream exhausts to the atmosphere.

The proper design and balance of local exhaust systems, including hooding and ducting, are required to assure that a collection system effectively controls discharge of particulates to the atmosphere. Process equipment should be enclosed as completely as practicable, allowing access for routine maintenance and inspection. Generally a minimum indraft velocity of 61 meters per minute should be maintained through all open-hood areas (37). Proper design of hoods and enclosures minimizes exhaust volumes required and, consequently, power consumption. Proper hooding also minimizes the effects of cross drafts (wind) and induced air (i.e., air placed in motion as a result of machine movement or falling material). Good duct design dictates that adequate conveying velocities be maintained to prevent transported dust particles from falling out and settling in the ducts en route to the collection device. Information on crushed stone recommends conveying velocities for mineral particles in the range of 1100 to 1400 meters per minute (37).

For proper dust control from process sources, hoods should be installed at conveyor transfer points, screens, crushers, grinders, and bagging operations. The fabric filter or baghouse is the most effective dust collection device in the mineral industry. Most crushing plants use mechanical shaker-type collectors, which require periodic shutdown for cleaning (after four or five hours of operation). These units normally are equipped with cotton sateen bags and operated at an air-to-cloth ratio of two or three to one. A cleaning cycle usually requires no more than 2 to 3 minutes of bag shaking, which is normally actuated automatically when the exhaust fan is turned off.

For applications where turning off the collector is impractical, continuous-cleaning fabric filters are used. Jet-pulse units are preferred over compartmented mechanical shakers. Jet-pulse units ordinarily use wool or synthetic felted bags for a filtering medium and may be operated at a filtering ratio of as high as six or ten to one. With either type of baghouse, greater than 99 percent efficiency can be attained, even on submicron particle sizes (38).

Other collection devices include cyclones and low-energy scrubbers. Although these collectors demonstrate high efficiencies (95 to 99 percent) for coarse particles (40-micrometer and larger), their efficiencies are poor (less the 85 percent) for medium and fine particles (20-micrometer and smaller) (38). High-energy scrubbers and electrostatic precipitators could conceivably achieve results similar to that of a fabric filter, but these methods do not appear to be used in the industry.

LIQUID WASTES AND CONTROL TECHNOLOGY

Liquid Wastes

Liquid wastes from construction materials and non-ferrous metals mining show one major difference: effluent from construction materials generally contain only suspended inert solids, whereas effluents from nonferrous metals are often acidic and contain dissolved heavy metals (29, 39).

Liquid wastes come from three major sources:

1) Mine dewatering: For many mines this is the only source of wastewater. It is usually low in suspended solids, but may contain dissolved minerals or metals (29, 39).

2) Process waters: This is water used in transportation, classification, washing, beneficiation, separation, and processing of ores. The effluent usually contains heavy loadings of suspended solids, and in nonferrous metals mining, dissolved metals (39).

3) Precipitation runoff: Since mining operations require large surface areas, precipitation constitutes a major source of wastewater and pollutant loading. This water also contains suspended solids such as minerals, silt, sand, and clay, and possibly hazardous metals, depending on the type of ore mined (39).

Other major sources of water pollution primarily associated with mining and beneficiation operations are acid mine drainage and tailings pond leakage. Surface runoff near beneficiation and processing facilities is another potential problem area.

Acid runoff can be produced by the leaching of precipitation through any mine waste containing sufficient pyrite or other sulfide. The presence of heavy metals compound the pollution potential because at a low pH, the metals tend to dissolve in the water (40, 41).

Solid wastes are commonly disposed of in tailings ponds. Wastewater streams are also treated in these ponds. The supernatant decanted from these tailings ponds contain suspended solids and sometimes cyanide or ammonia introduced to the water during ore processing (42).

Percolation of wastewater from impoundments may occur if tailings ponds, settling ponds, and lagoons are not designed properly (29).

Construction Materials--

Liquid wastes generated by construction materials mining are primarily from mine dewatering, ore processing, and precipitation runoff. They usually contain only inert suspended solids. Process water and mine dewatering are controlled and contained by pumping or gravity flow through pipes, channels, ditches, and ponds. Surface runoff near ore processing facilities, haul roads, conveyors, and storage piles are a potential pollution source also. Surface runoff is generally untreated; however, methods used to minimize erosion control suspended solids loadings in the effluent (39). Usually no further treatment is necessary to achieve a high effluent quality from tailings ponds if the ponds are well-designed and the water does not contain excessive concentrations of dissolved metals or other undesirable ions (29, 42, 43).

Relative quantities and composition of the wastewater generated vary from one mining category to another. Chapter 4 deals specifically with wastewater characteristics.

Nonferrous Metals--

Although effluents from the mining and processing of nonferrous ores generally contain such hazardous metals as lead, copper, zinc, and nickel, these materials can be controlled to acceptable levels by established waste management practices. Wastewater generated by such ore processing operations as concentration, separation, and beneficiation are generally alkaline and often contain dissolved metal ions and process reagents, i.e., cyanide, methanol, and ammonia. Usually these waste streams are discharged to a tailings pond for pH control and solids settling. The supernatant is either treated before discharge or is recycled to the mill. Partially oxidized sulfur compounds may be present in mill effluent; unless they are stabilized in a waste treatment system, they can cause acidic conditions miles from the point of discharge (40).

Acid mine drainage is often a problem in mining nonferrous metals because the ores usually contain sulfur compounds. The impact of acid mine drainage depends on whether a pyrite is associated with the ore being mined and the control techniques applied to minimize acid formation.

Relative quantities and composition of these wastewater sources vary from one mining category to another. Chapters 4 and 5 of this report contain more specific information on this subject.

Control Technology

Control of water pollution can be achieved by proper mining and land reclaiming methods, minimizing water contamination at the source, and treating of effluents in well-designed and maintained facilities.

Control of contaminated runoff can be maintained effectively by diking and diverting the surface flow to prevent the runoff from higher elevated or undisturbed areas from coming in contact with exposed surfaces, to reduce the surface flow velocity, and to divert the contaminated runoff through sediment-detention structures. These methods also minimize erosion (44).

The now extensive reclamation of mined-out areas not only has aesthetic value but also reduces water pollution potential. Sometimes the land is landscaped and revegetated; at other times recreational lakes are developed from abandoned open-pit mines. Other reclamation alternatives are physical-chemical soil stabilization and soil amelioration (43).

The most common method of treating process wastewater is to discharge it into the tailings pond to settle out the suspended solids. Although discharge from the pond is usually of acceptable quality to recycle or discharge, secondary treatment could be necessary. Secondary treatment methods include clarifiers, aerators, thickeners, and liming, which are installed for tailings pond supernatant and/or process wastewaters. When the effluent must be of high quality, it can be treated further by ion exchange or reverse osmosis to remove dissolved metals.

Construction Materials--

Treatment and control of wastewaters generated from the mining and milling of construction materials are normally not as critical or complex as for nonferrous metals. Many mines have only mine dewatering discharge. Discharges from tailings disposal areas are sometimes a problem because of decreased residence time during high-flow periods. Chemical flocculation, thickeners, clarifiers, centrifuges, and other suspended solids removal techniques are rarely used (39).

The following are wastewater treatment methods for construction materials:

Settling ponds--Settling ponds are widely used to remove total suspended solids (TSS) because they are easier to construct and less expensive to operate than other technologies. Effectiveness depends on the settling characteristics of the solids and the retention time. Settling ponds generally achieve reductions in TSS to 50 milligrams per liter or less; however, for some wastewaters, the TSS content of the discharge is as high as

150 milligrams per liter. Most facilities achieve a 95 percent or better reduction in TSS. Settling ponds also provide equalization, water storage capacity, and solid waste storage.

Flocculation--Flocculating agents, such as ferric chloride ($FeCl_3$), alum [$AlNH_4(SO_4)_4$], and ferrous sulfate ($FeSO_4$), and a variety of polyelectrolytes increase the efficiency of settling facilities and are most often used after the larger, more readily settled particles have been removed.

Clarifiers and thickeners--Clarifiers or thickeners are sometimes used to remove suspended solids. Consisting primarily of tanks with internal baffles to provide efficient concentration of solids and clarification of the liquid, these devices are usually used by phosphate and industrial sand operations when sufficient land for ponds is not available or when suspended particles are too small to settle under gravity and flocculating agents must be added.

pH control--Since some wastewaters, including mine drainage, are either acidic or alkaline, they need to be brought to a pH of 6 to 9 before disposal or discharge. Acidic streams are usually treated with alkaline materials such as limestone, soda ash, sodium hydroxide, or lime. Alkaline streams are treated with an acid such as sulfuric acid. Dissolved solids such as lead, zinc, copper, manganese, and iron, are precipitated as hydroxides. Lime is the most widely used reagent for acid water.

Precipitation--Sulfates, fluorides, hydroxides, and carbonates can be precipitated by lime treatment (39). Sodium sulfate is used to precipitate copper, lead, and other toxic metals. The suspended precipitates are then removed by settling ponds, clarifiers, or thickeners, along with flocculating agents if necessary.

Nonferrous metals--

Wastewaters generated from various beneficiation processes are commonly discharged to a tailings pond to control pH. Heavy metals are precipitated as hydroxide when pH is raised with limes. Consistently high effluent quality can reach pH ranges from 9.5 to 10.5 to precipitate copper, lead, zinc, and nickel compounds.

Process wastewaters can also be treated with a mechanical system, which includes settling, flotation, aeration, and less frequently, reverse osmosis or ion exchange. Cyanide and ammonia used as flotation agents in the milling process may form toxic compounds and residuals that cannot be stabilized in the waste treatment system. The use of these compounds is discouraged (41).

The use of tailings impoundments is becoming less attractive because of acid generation and metal leaching, which cause long-term seepage problems and prevent vegetation of the area.

In control of water pollution, emphasis should be placed on minimizing water usage and discharges and preventing pollution at the sources.

The use of settling ponds, pH control, clarifiers, thickeners, flocculation, and precipitation, as described under Construction Materials, are also used in nonferrous mining and beneficiation operations. Other treatment methods include oxidation, adsorption, and reverse osmosis. These methods are described in the following paragraphs:

Precipitation--Starch xanthate complexes are reported to be effective in aiding precipitation of a variety of metals, including cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc (45). Oxidation can be used in conjunction with starch xanthate in special cases to produce less soluble heavy-metal products.

Oxidation--Several waste components produced by mining and beneficiating of nonferrous materials can be removed or rendered less harmful by oxidation (39). Among these are cyanide, sulfide, ammonia, and other compounds that cause high chemical oxygen demand (COD) levels. Cyanide can be removed effectively by rapid chlorination at a pH of 10.5. Generally when high COD levels are occurring, aeration or the use of strong oxidants are of value.

Adsorption--The application of activated carbon adsorption to mining and processing wastewater treatment is more limited by cost than feasibility (39). The removal of flotation reagents or solvent extraction compounds is practical in some operations if the waste streams are segregated.

Ion exchange--Ion exchange equipment will remove various ionic species (39). The disadvantages of using ion exchangers to treat wastewaters generated by mining and beneficiating operations are high costs, limited resin capacity, and inadequate specificity. The feasibility of applying ion exchangers depends upon the resin loading achievable and pretreatment required. Waste segregation and recycling enhance the practicability. Since calcium ions are usually present in greater concentrations than other metal ions, this method would not be feasible.

Reverse osmosis--A reverse osmosis plant for acid mine drainage consists of pumps and filters for removal of suspended solids (43). Effluent from the filter enters a pressure chamber at the point of exposure to the membrane cells. Concentrated brine passes from the unit and is treated or injected into a deep well. The product water can be brought to potable quality by a small increase in pH. Very high removal of dissolved solids, sulfates, calcium, magnesium, and iron has been achieved by reverse osmosis, but this method is not economical unless acid mine drainage is to be used to supply potable water for municipal use.

SOLID WASTES AND CONTROL TECHNOLOGY

Solid Wastes

In the mining industry, the major solid waste disposal problem involves handling and relocation of overburden and gangue. Overburden is the rock which overlies the ore body in open pit, underground, and strip mines. In beneficiation operations such as screening and concentrating, the solid wastes generated (tailings) essentially consist of the host rock. Other solid wastes are produced from wastewater treatment and air pollution control systems. All solid wastes that cannot be recycled within a process must ultimately be disposed of by landfilling or by impoundment on the surface (43).

Since huge volumes of wastes are produced, large-scale impoundment facilities must be maintained. In underground mining operations, the trend is to return the coarse tailings to the areas underground as they are mined out and abandoned (29).

Characteristics of solid wastes from mining and beneficiating operations vary according to industry and location.

Aside from the problem of containment, solid waste impoundments pose a potential water pollution problem in the form of runoff, seepage, and leaching. Tailings pond effluent, as discussed earlier, has an acid-generating potential that can cause metal dissolution.

Solid wastes from the mining of construction materials and nonferrous metals are discussed below.

Construction Materials--

Generally, tailings and gangues from construction materials, mining, and ore processing are relatively inert. Solid wastes are impounded perpetually in tailings pond, and effluent from the pond usually requires no additional treatment.

Nonferrous Metals--

Solid wastes generated from nonferrous metals mining are generally more hazardous than those from construction materials mining. If the solid waste contains sufficient pyrite, sulfuric acid can be generated and heavy metal can be leached out of the rocks, as discussed earlier.

Control Technology

In general, the industry produces large quantities of solid waste. Certain mining techniques can be used to minimize solid waste generation; however, properly designed and maintained containment and treatment facilities are necessary. Tailings that contain a sufficient percentage of course materials (sands) can be separated and the course sands used as embankment material for the fines.

Impoundment basins must be designed to reduce or prevent leakage, seepage, groundwater percolation, infiltration, and overflow. Effluent sometimes requires additional treatment before it is discharged to a stream or recycled to the process. Dikes must be designed so as to maximize stability, and if solid residue piles are not managed properly, they constitute sources of fugitive dust and stream sediment in runoff. Vegetative stabilization is often used to minimize these problems (39).

The principal methods of solid waste utilization are discussed in the following paragraphs.

Revegetation--Implanting a vegetative cover on mineral mining wastes or mined areas is called revegetation. This method serves to stabilize erodible slopes, minimize water pollution, control dust, and facilitate crop-producing potential.

Chemical and physical waste stabilization--Chemical and physical waste stabilization of mine wastes is sometimes used instead of revegetation to minimize fugitive dust and water pollution (43). Also, chemical stabilization is often used in conjunction with vegetation to protect the plants.

Physical stabilization is a method that involves covering the wastes with erosion-resistant waste rock from the mining operation, when it is available. Coverage with topsoil and bark is also considered a physical method that offers aesthetic advantages.

Chemical stabilization ranges from the use of soil sealants to the application of fertilizers for amelioration of soil to enhance plant growth. Chemical stabilizers, however, are generally defined as chemical agents that bind waste surfaces to prevent erosion. The main advantage of chemical stabilizers is that they protect the vegetative covers during early stages of growth. They normally cannot be expected to be permanent.

Soil Amelioration

Amelioration of soil properties is essential before revegetation on some mine wastes. Salinity, pH, and nutrient content are critical factors that require amelioration. Some ameliorating agents that increase pH are lime, crushed limestone, asbestos, tailings, fly ash, and sewage. Agents that decrease pH are pyrite-rich tailings, powdered sulfur and acids. Nutrients can be added by fertilizing or applying sewage sludge.

Construction Materials--

Solid waste disposal techniques are not significantly different from those just discussed. Wastes generated from this category are generally less hazardous and pose fewer environmental problems than nonferrous metals mining. When acid mine drainage is a potential problem, special attention to disposal methods and maintenance is needed. Sometimes, too, specific problems are associated with certain mining categories. In asbestos mining, for example, asbestos fibers in the solid waste present fugitive dust and water pollution problems if not managed properly.

Nonferrous Metals--

Although impoundments are often the only alternative, they become unattractive when tailings contain significant concentrations of pyrite or similar sulfides that lead to acid generation and leaching of metal values. Long-term environmental problems are prevalent and difficult to solve (41).

The processing of tailings to recover the metal values has been found to be economically infeasible. With the combined effect of higher market values, improved technologies, and long-term environmental implications, metal recovery may become more attractive in the future (41). Some reworking of tailings occurred when flotation technology replaced the gravity separation techniques of early mining days. Hydrometallurgy may produce an analogous activity in the future.

Rehabilitation includes revegetation of tailings areas; control of contaminated surface, mine pit, and underground discharges; control of mining subsidence; improvement of the general aesthetics; and area redevelopment (41). The uptake of toxic materials in the vegetation is a source of concern where vegetation can be harvested or consumed by wildlife or domestic animals.

HAZARDOUS WASTES (43, 46, 47)

The term hazardous wastes means any waste or combination of wastes which pose a substantial present or potential hazard to human health or living organisms because such wastes are lethal, nondegradable, persistent in nature, biologically magnified, or otherwise cause or tend to cause detrimental cumulative effects. General categories of hazardous wastes are toxic chemicals, flammable, radioactive, explosives, and biological. These wastes can take the form of solids, liquids, gases or sludges.

There are numerous sources of hazardous wastes in the mining of construction materials and nonferrous metals. These wastes could originate from the mining or extraction of the ore, processing of the ore and as the constituents of waste streams. These wastes may be in the form of fugitive particulates, gaseous and liquid wastes as well as solid wastes.

The toxicity and adverse environmental effects of some of the potentially hazardous materials associated with the mining activity are summarized below:

- Solid wastes from mining activities, which consist mainly of overburden and gangue are in general not toxic; however they may be hazardous to health on another basis (e.g. asbestiform minerals) or become a source for toxic emissions as they weather and otherwise alter with time to give up undesirable chemicals.
- The most significant source of liquid wastes in the mining industry is acid mine drainage. Acid mine drainage can be extremely damaging to aquatic life. Heavy metal (copper, nickel, lead, zinc) ions found in acid mine drainage are often in concentrations sufficient to be harmful or even toxic to aquatic life. At pH levels below 5, most fish life dies.
- Particulates generated as a result of mining of asbestos are a known health hazard in air and possibly water.
- Cyanide is used as a flotation reagent in many base metal mines, including cyanidation circuits for gold extraction. Cyanide is highly toxic and its use is generally discouraged in favor of alternate reagents.
- Free silica which is emitted as fugitive dust from sand and gravel operations may result in development of a pulmonary fibrosis (silicosis) if exposed for a prolonged time.

- Mill effluent has characteristics that have a chemical or a biochemical oxygen demand, some of which may be toxic to animals or plants.

- Milling practices for the recovery of gold may produce a cyanide-leach problem. Process wastes from mining activities are often ponded at many facilities. There is a strong tendency for leaching out heavy metals to nearby streams, which can make it unsuitable for fish and other aquatic organisms.

- Toxic effects caused by the discharge of reagents or residuals other than heavy metals can alter the receiving stream environment making it unsuitable for habitation by native biota.

SECTION 4

NONMETALS

DIMENSION STONE

Industry Description

"Dimension stone" is rock which has been specially cut or shaped for use in buildings, bridges, curbing, and other construction or for special applications. Large quarry blocks suitable for cutting to specific dimensions also fall into this classification. The principal dimension stones are limestone, granite, marble, sandstone, slate, and basalt.

The dimension stone industry accounted for less than 0.5 percent of total stone output in 1974, and 4 percent of the total value. It consisted of approximately 500 plants in 44 states and produced $100 million worth of construction, monumental, and speciality products (1). Section 1 presents production statistics for dimension stone.

Nearly every state in the Union produces dimension stone. Igneous and metamorphic rocks are predominant in the Appalachian and Rocky Mountain belts, but granite is also produced in Missouri and in several of the North-Central states. Nearly all of the slate now comes from six Atlantic states from North Carolina to Maine, however, a small quantity is still produced in Utah. Michigan and several southern states also produced small amounts in the past. Limestone and sandstone are the predominant dimension stones in the sedimentary formations of the Midwest and also occur widely elsewhere in the United States.

Construction consumes more than 75 percent of the dimension stone in the United States, with exterior and interior facing panels for buildings taking the major share. Curbing, flagging, and slate roofing comprise the other significant construction uses. Monument works consume another 20 percent of the dimension stone output, mostly for gravestones and markers. Miscellaneous uses that account for the rest of the output include slate, electrical panels, blackboards, billiard tabletops, and various decorative panels for furniture, such as tops for dressers and tables (1).

Clays, lithium, and gypsum are the only significant by-products in dimension stone production. Flake mica, which occurs in igneous and metamorphic rocks, is a potential by-product worthy of attention. Stone is obtained in conjunction with production of many metallic and nonmetallic ores (1).

Process Description

Dimension stone is obtained from open-pit quarries. (Figure 11 presents a simple diagram of the steps involved in its mining and beneficiation.) Quarrying can be accomplished by one of the following techniques (39):

- Drilling with or without broaching
- Channeling by machine (semi-automated, multiple-head chisels)
- Sawing with wire
- Using low level explosives
- Using high-velocity jet flames to cut channels
- Using splitting techniques

After a large block of stone is freed, it is either hoisted onto a truck and driven from the floor of the quarry to the processing facility, or it is removed from the quarry by means of a derrick, then loaded onto a truck.

At the processing facility (usually located at or near the quarry) the blocks of stones are first sawed into slates by gang saws, wire saws, or, occasionally, rotating diamond saws. All sawing systems require considerable water for cooling and particle removal; however, the water is usually recycled.

After the blocks have been sawed into slabs of predetermined thicknesses, they are ready for finishing. Finishing operations vary and depend either on the properties of the stone itself or on the characteristics of the end product. Some of the finishing operations are splitting, trimming, and polishing (39).

Waste Streams

Table 7 presents a summary of multimedia wastes from the mining and beneficiation of dimension stone, and the following paragraphs explain in more detail the various air, liquid, and solid wastes associated with this industry.

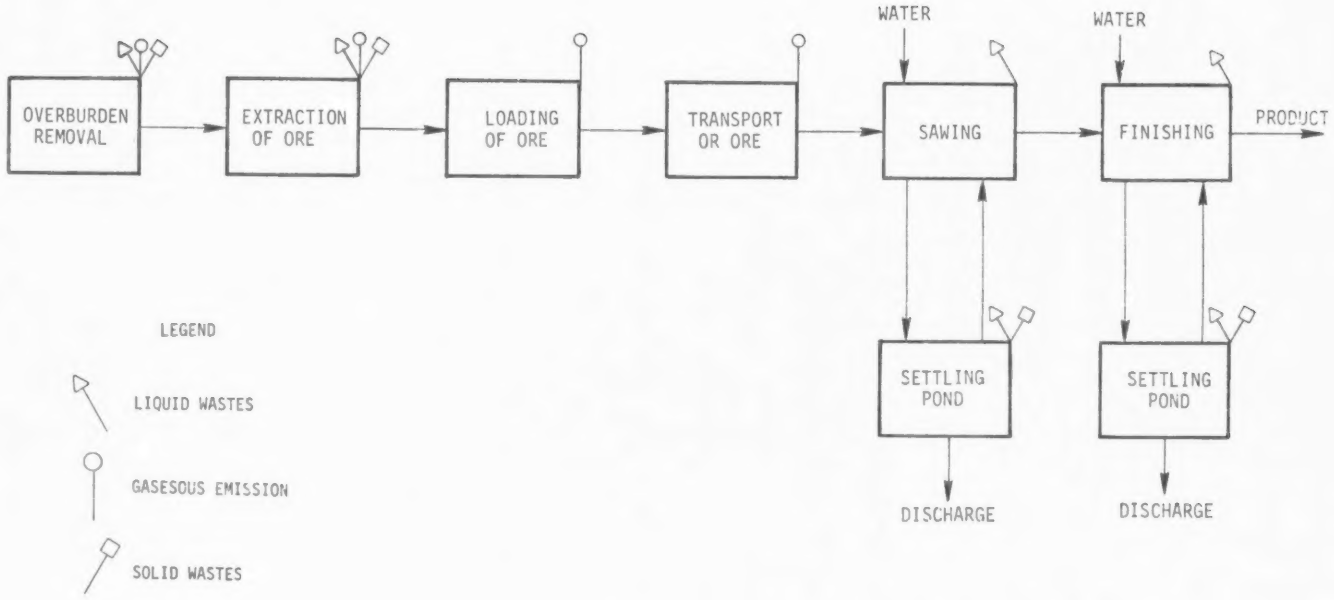

OVERBURDEN REMOVAL
EXTRACTION OF ORE
LOADING OF ORE
TRANSPORT OR ORE
WATER
SAWING
WATER
FINISHING
PRODUCT
SETTLING POND
DISCHARGE
SETTLING POND
DISCHARGE
LEGEND
LIQUID WASTES
GASESOUS EMISSION
SOLID WASTES

Figure 11 . Mining and beneficiating of dimension stone.

TABLE 7. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF DIMENSION STONE

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal	Particulates	N.A.	Overburden removal	TSS	< 25 mg/ℓ[a]	Overburden removal	Waste rock	N.A.
Ore extraction			Ore extraction			Ore extraction		
Ore loading			Sawing	TSS	N.A.	Settling pond	Sludge	N.A.
Ore transport			Finishing	TSS	N.A.			

[a] Ref. 39.

N.A. - Not available.

Air Emissions--

The quarrying operation is the major source of air emissions in the dimension stone industry, as all other operations are accomplished using water. No data are available on the quantity of particulate emissions however.

Liquid Wastes--

Pit pumpout is a seasonal occurrence in some dimension stone facilities. The quality of the mine water depends more on stone type than any other factor. For example, pumpout at one granite quarry contains 26 mg/liter total suspended solids. However, limestone, marble, and dolomitic limestone quarry water is generally very clear and much lower in suspended solids (39). Most limestone and some granite quarries use water for channel cutting and water is also used in small quantities during wet drilling.

All sawing operations require water. The raw waste load from these operations contains a significant load of suspended solids, as do the untreated effluents from finishing facilities. Sawing and the finishing operations are often under the same roof and water effluents are combined.

Water usage varies according to stone processes, water availability, and owner or operator attitudes on water usage. Table 8 shows water usage data for various dimension stone facilities (39).

TABLE 8. DIMENSION STONE WATER USE DATA

Stone type	Water use, liter/Mg of stone processed	
	Saw plant	Finish plant
Mica Schist	4,460	None
Limestone	16,600	1,600
Granite	7,350	7,360
Marble	100,000	Unknown

Source: Ref. 39.

Solid Wastes--

Overburden and waste rock are generated from the quarrying operation. Another source of solid wastes is the settling pond, which generates sludge. Quantitative data on these wastes have not been reported.

Control Technology

Control technologies applied to the dimension stone industry are explained in the following paragraphs.

Air Emissions Control--

Particulate emissions from quarrying operations and haul roads are controlled by wetting.

Liquid Waste Control--

Effluent from the quarry is discharged into a sump for continuous recycling and is rarely discharged.

Wastewater from both sawing and finishing operations is first discharged into a settling pond, where most of the suspended solids are allowed to settle out. Sometimes effluents from these operations are combined and discharged into a common pond. The settling pond is reported to reduce total suspended solids by more than 96 percent (39). Treated wastewater is recycled as process water.

Solid Waste Control--

The overburden and waste rock from quarrying operations is either stockpiled on site or crushed and screened to smaller sizes for use as aggregates.* Settling pond sludge is hauled to an on-site dumping area, where runoff water is controlled to reduce TSS levels to any nearby streams.

Conclusions and Recommendations

Environmental impacts from the dimension stone industry are minor compared to the crushed stone industry. Air, liquid, and solid wastes are amenable to conventional treatment technologies.

Effluent from sawing and finishing operations is sent to settling ponds (usually in series) for treatment. Sludge that accumulates in the pond is removed periodically and disposed of on-site. The properties of the sludge are such that bricks might possibly be made from it. Using sludge and other solid waste for this purpose warrants further investigation to determine its technical and economic feasibility.

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*Telephone conversation between Vijay Patel of PEDCo and Mr. Max Jurras, Division of Air and Solid Wastes, State of Vermont, Montpelier, Vermont. April 1977.

CRUSHED STONE

Industry Description

Crushed stone is derived principally from limestone, dolomite, granite, trap rock, sandstone, quartz, and quartzite (48). Less than 5 percent comes from calcereous marl, marble, shell, and slake.

Crushed and broken stone refers to rock that has been reduced in size after mining to meet various consumer requirements (1). The United States is the leading producer of crushed stone, and this industry is responsible for more than 99 percent of all stone produced in this country. Firms range in size from small independent producers with single plants to large diversified corporations with 50 or more plants. Plant capacities range from less than 2.27 x 104 to about 1.36 x 106 megagrams per year (1). Section 1 presents production statistics for crushed stone.

Plants are widespread geographically, with all but one state reporting production in 1974. Crushed granite comes primarily from the Rocky Mountain and Appalachian areas, basalt from the northeast sections of the Rocky Mountains and Hawaii (where it is the principal crushed stone), and shell from the Gulf Coast and Atlantic Coast States. Arkansas, California, and Pennsylvania produce over half of the total output of quartzitic stone, and the balance of the production is scattered over 32 other states (1).

Construction consumes 86 percent of the crushed stone produced in the United States, with highway construction leading in quantity, followed by building construction. All major types of crushed stone (limestone, quartzite, granite, etc.) are used for construction. Closely related to the direct construction use is the quantity that goes into cement production. Crushed stone is also used as a source of calcium in agriculture; as flux in the iron and steel industry; as a water softening agent; and in the making of glass, refractories, and chemicals.

The only significant by-products are clays, lithium, and gypsum. Some stone is obtained in conjunction with the production of metallic ores and nonmetallic minerals. Although most of it is dumped as waste for lack of local demand, small quantities are marketed.

Process Description

Although most crushed and broken stone is presently mined from open quarries a trend is growing in many areas toward large-scale production by underground mining methods. In 1974 about 5 percent of all crushed stone production came from underground mines (1). Shell dredging, mainly from coastal waterways, accounts for approximately 1 percent of total production (39). The crushed stone is beneficiated by both dry and wet processes.

In the quarrying operation, the overburden is removed and the raw material is loosened by drilling and blasting. The steep, almost vertical walls of the quarry may be several hundred meters deep. The mine is normally excavated on a number of horizontal levels (called benches) at various depths. The material is loaded into trucks for transport to the processing facility. Occasionally a portable processing facility, which can be situated near the blasting site, is set up on one of the quarry benches or on the quarry floor. Specific methods vary with the nature and location of the deposit (39).

At the processing facility (Figure 12) the raw material passes through screening and crushing operations before final sizing and stockpiling. Consumer demands for various product grades determine the number and position of the screens and crushers. No process water is used in the crushing and screening of dry-process crushed stone.

Excavation and transportation of crushed stone for wet processing are identical to those for dry processing. The process is also the same except water is added to the system to wash the stone. This washing is normally done by spray bars that are added to the final screening operation after crushing. Since not all of the product is washed, a separate washing facility or tower is incorporated that receives only the material to be washed. This separate system usually consists only of a set of sizing screens equipped with spray bars. A portable processing facility can also incorporate a portable washing facility to satisfy the demands for a washed product.

Waste Streams

Table 9 summarizes multimedia wastes from the mining and beneficiation of crushed stone. The following paragraphs explain in more detail the various air emissions and liquid and solid wastes associated with this industry.

Air Emissions--

The major pollutant emitted during the production of crushed stone is respirable dust containing free silica. Both open-pit and underground mining activities generate considerable particulate emissions. Sources include drilling, blasting, secondary breaking, and loading and hauling of the minerals to the processing plant.

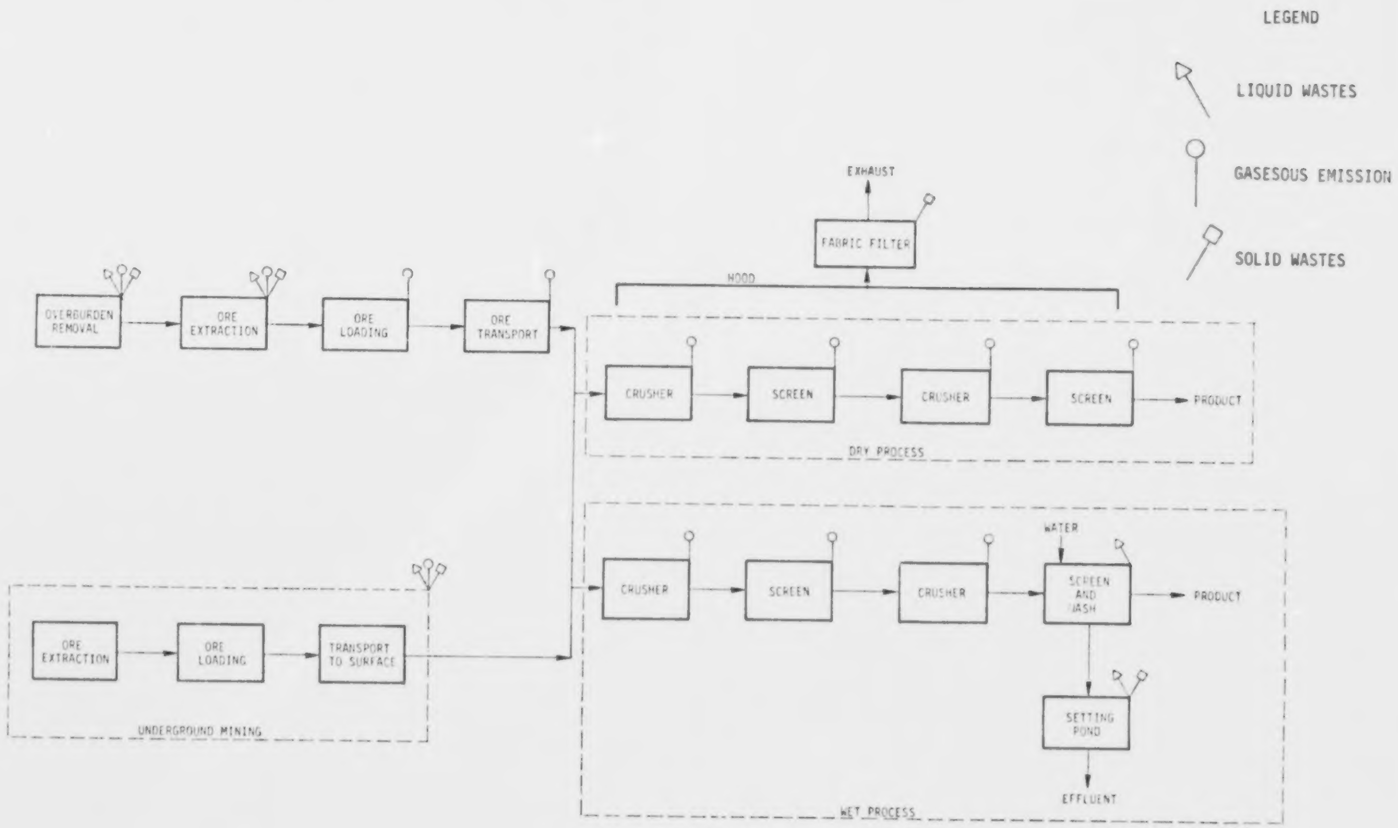
LEGEND
LIQUID WASTES
GASESOUS EMISSION
SOLID WASTES
EXHAUST
FABRIC FILTER
HOOD
OVERBURDEN REMOVAL
ORE EXTRACTION
ORE LOADING
ORE TRANSPORT
CRUSHER
SCREEN
CRUSHER
SCREEN
PRODUCT
DRY PROCESS
WATER
CRUSHER
SCREEN
CRUSHER
SCREEN AND WASH
PRODUCT
SETTING POND
EFFLUENT
WET PROCESS
ORE EXTRACTION
ORE LOADING
TRANSPORT TO SURFACE
UNDERGROUND MINING

Figure 12. Mining and beneficiating of crushed stone.

TABLE 9. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF CRUSHED STONE

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal	Fugitive particulates	N.A.	Overburden removal	TSS (Mine pumpout)	1 to 128 mg/ℓ	Overburden removal	Gangue	N.A.
Ore extraction			Ore extraction			Ore extraction		
Ore loading			Ore loading			Fabric filter	Particulates	N.A.
Ore transport			Ore transport			Settling pond	Sludge	N.A.
Underground mining	Fugitive particulates	N.A.	Underground mining					
Crusher	Particulates	0.25 to 3.04 kg/Mg[a]	Screen and wash	N.A.	N.A.			
Screen								

[a] Ref. 33.

N.A. - Not available.

Particulate emissions from drilling operations are primarily caused by air-flushing to remove cuttings and dust from the bottom of the hole. The level of uncontrolled emissions depends on the type of ore, its moisture content, the type of drill used, the diameter of the hole, and the penetration rate. Emissions from blasting depend on the size of the shot, blasting practices, mineral type, and meteorological conditions (especially wind). Emissions from secondary breaking are relatively insignificant (25).

Considerable fugitive dust emissions result from loading the product and hauling it over unpaved roads. The most significant factor affecting emissions during loading is moisture content of the ore. Although no data were found on hauling operations, an emission factor of 0.55 kilogram per vehicle kilometer has been reported for conventional vehicle traffic on unpaved country roads (33). It can be assumed that mineral hauling emissions are higher because of the greater size of the rubber-tired units and the finer texture of the typical road bed. Factors affecting fugitive dust emissions from hauling operations include the composition and wetness of the road surface and the volume and speed of vehicle traffic (25).

The generation of particulate emissions is inherent in the crushing process. These emissions, which are most apparent at crusher feed and discharge points, may be influenced by such factors as the moisture content of the rock, the type of rock processed, and the type of crusher used.

Dust is emitted from screening operations as a result of the agitation of dry stone. The level of uncontrolled emissions depends largely on particle size of the material screened and the amount of mechanically induced energy. Emission factors for various crushing and screening operations are shown in Table 10.

TABLE 10. PARTICULATE EMISSION FACTORS FOR STONE CRUSHING PROCESSES

Process Operation	Uncontrolled emission factor, kg/Mg of ore processed
Primary crushing	0.25
Secondary crushing and screening	0.76
Tertiary crushing and screening	3.04

Source: Ref. 49.

Liquid Wastes--

Mine pumpout is the major source of liquid wastes in both open-pit and underground mines. Mine water comes from groundwater, precipitation, or surface runoff. Data from several mines indicate a total suspended solids range of 1 to 128 parts per million (39).

The dry process does not produce any other liquid wastes. In the wet process, however, the crushed stone is washed by spray bars in the final screening operation. The quantity of water required for washing depends upon the deposit from which the raw material is extracted. The quantity of wash water reported in several facilities has ranged from 0.041 to 1.26 cubic meters per megagram of product (39).

Solid Waste --

Overburden and gangue are the major sources of solid wastes in open-pit and underground mines. Although typical overburden ranges from 0.9 to 1.5 meters, it can be as high as 3 to 4.5 meters.*

Other sources of solid wastes include the dust collected by the dry collection device (fabric filter) and sludge accumulation in settling ponds. Quantitative data on these wastes are not available.

Control Technology

Control technologies applied in the crushed stone industry are covered in the following paragraphs.

Air Emissions Control--

Water injection and aspiration to a control device are the two methods normally used to control particulate emissions from drilling operations. The most common control devices are cyclones or fabric filters preceded by a settling chamber. Whereas collection efficiencies of cyclones seldom exceed 80 percent, the efficiencies of fabric filters are usually over 99 percent. Air volumes required for effective control range from 14 to 42 cubic meters per minute depending upon the type of rock drilled, the hole size, and the penetration rate (48).

No effective method for controlling particulate emissions from blasting is yet known; however, good blasting practices can minimize the effects of noise, vibration, air shock and dust emissions.

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*Telephone conversation between Vijay Patel of PEDCo and Frederick Allen, North Carolina Aggregate Association, Raleigh, North Carolina. April 1977.

Wetting the rock prior to loading helps to control fugitive dust from loading operations. This is done with water trucks equipped with hoses or movable watering systems (48).

Various road treatments used to control fugitive emissions from haulage roads include watering, surface treatment with chemical dust suppressants, soil stabilization, and paving.

Process emissions from crushers, screens, conveyor transfer points and storage facilities are controlled by devices such as wet dust suppression, dry collection, and a combination of the two. The wet dust suppression device introduces moisture into the material flow, causing fine particulate matter to be confined and remain with the material flow rather than become airborne. Dry collection involves hooding and enclosing dust-producing points and exhausting emissions to a collection device. Using enclosed structures for process equipment is also an effective means of control (48).

Hooding and air volume requirements for the control of crusher emissions vary greatly according to judgment and experience. The only established criterion is that of maintaining a minimum indraft velocity of 61 meters per minute through all open hood areas (48).

Screening operations generally apply a full coverage hood to control emissions. Required exhaust volumes vary with the surface area of the screen and the amount of open area around the periphery of the enclosure. A minimum exhaust rate of 15.56 cubic meters per minute per square meter of screen area is commonly used, with no increase for multiple decks (1).

The most commonly used dust collection device in the crushed stone industry is the fabric filter, which is more than 99 percent efficient. Other reported collection devices include cyclones and low energy scrubbers (48).

Liquid Waste Control--

Pit pumpout is discharged directly without treatment, discharged after treatment, or discharged along with treated effluent from the washing operation. In this last method, quarry water combines with the untreated facility effluent and then flows through a settling pond system prior to discharge. In this type of facility, much of the combined pond water is recycled rather than discharged (39).

All facilities send effluent from washing operations through a settling pond system prior to discharge. The system design generally includes at least two settling ponds in series to reduce the suspended solids in the final discharge to less than

50 milligrams per liter. Reduction in the concentration of suspended solids has been reported to exceed 95 percent (39). Many facilities recycle a portion of their treated effluent. In many instances, evaporation and percolation tend to reduce the flow rate of the final discharge.

Solid Waste Control--

The solid waste (overburden) from open-pit mining is either stockpiled on site or used in reclamation. Small quantities of solid waste from underground mining operations are usually left within the mine site.

The large quantities of solids collected in the fabric filters are sometimes marketed. When a market is not available, the waste is dumped on site. Sludge from the settling ponds is also disposed of on site. These wastes can cause an adverse environmental impact if they become airborne or if harmful constituents wash into surface waters and leach into groundwater.

Conclusions and Recommendations

Treatment technologies currently available in the crushed stone industry are generally adequate to maintain environmental standards.

An area that might be researched is locating a steady market for sludge from the settling ponds and particulate matter collected in the fabric filter.

CONSTRUCTION SAND AND GRAVEL

Industry Description

On a product weight basis, the sand and gravel industry is the second largest nonfuel mineral industry in the United States. Historically, these products have been the principal construction materials in the United States, and from all indications they will continue to be. The industry is one of the fastest growing in the mineral field, producing enough sand and gravel to satisfy the total domestic requirement. Every state in the Union reported some production in 1974, and active or latent deposits are located in nearly every county. Although resources are inexhaustible on a national basis, some local shortages exist.

Since sand and gravel are produced by weathering of rock, they are predominantly silica; however, they often contain other minerals such as iron oxides, mica and feldspar. The particle size of sand ranges from 0.065 to 2 millimeters, whereas gravel consists of naturally occurring rock particles larger than 4 millimeters but less than 64 millimeters in diameter (2). Particles finer than sand are referred to as silt, and particles larger than gravel as cobbles and boulders.

In 1974, 4844 sand and gravel companies operated 6697 separate facilities. Annual production of individual companies varies greatly (the range was 4.54 to 3.63×10^6 megagrams in 1974), but the average company is small (2).

Total sand and gravel resources that can be reached at current exploritation costs are estimated to be 5.90×10^{10} megagrams which is adequate to meet the projected cumulative requirements through 2000 (3.61×10^{10} megagrams). By 2000, approximately half of the sand and gravel requirements will still come from deposits of material similiar to those now being exploited and the remainder from lower grade deposits and possibly offshore resources.

The sand and gravel industry extends into every state. Production in 1974 ranged from 1.1×10^8 megagrams in California to about 9.9×10^5 megagrams in Hawaii. Following California, the next five states in terms of total output are Wisconsin, Michigan, Illinois, Ohio, and New York.

Sand and gravel have both construction and industrial uses. However, construction consumes more than 95 percent of the total volume, leaving less than 5 percent for industrial applications. Specific uses of construction sand and gravel are covered in this section; industrial uses will be covered later under Industrial Sand.

The end use of construction sand and gravel is determined by such factors as the ratio of sand to gravel, particle size, particle shape, rock type, and chemical composition. Sand and gravel can be used directly after limited processing (e.g., cleaning and sizing) or mixed with other materials to form a different product, such as portland cement. In 1974, highway and street construction accounted for 63 percent of the total demand. Sand and gravel aggregates go into concrete and bituminous paving mixes, concrete structures such as bridges and tunnels, road-base material, and fill. As the second largest consumer, general building and other heavy construction industries accounted for about 25 percent of the total 1974 demand. Most of the sand and gravel is used as aggregate in concrete, with small quantities used for fill, septic fields, and other building construction purposes. About 7 percent is consumed by the building industry for concrete construction materials such as brick and concrete block.

Although sand and gravel generally are used in combination as a single product, they can be used separately. Sand has the wider range of usage. It is used in architectural structures, mortar, plaster, all forms of road and pavement construction, and for purposes other than construction.

Almost no by-products or coproducts are recovered in the sand and gravel industry. Traces of gold and silver have been recovered during extraction, but quantities are miniscule. Potential salable by-products/coproducts include heavy minerals, flake mica, and clay, but little attempt has been made to recover any of these (2). The increasingly stringent regulations on land disturbance and solid waste disposal may soon require more complete recovery of salable materials.

Process Description

Sand and gravel producers may turn out one product or a range of products. Some operations sell only bank-run material, which requires no processing, whereas others sell material that has been subjected to various processing techniques. Most producers are engaged exclusively in the sand and gravel business, but some are diversified.

When sand and gravel deposits are large, permanent installations are built and operated for many years. Portable and semiportable units are used in pits that have an intermediate working life. Many facilities operate year round, and others operate on a limited basis depending on such factors as weather and/or product demand.

Sand and gravel are usually found in the same deposit, but proportions vary greatly. This sand to gravel ratio, the chemical and physical characteristics of the gravel deposit, and the specifications of the user govern extraction and processing equipment/methodology at a specific site.

Currently, three methods of sand and gravel excavation are practiced: (1) dry pit (sand and gravel are extracted above the water table); (2) wet pit (raw material is extracted by means of a dragline or barge-mounted dredging equipment both above and below the water table); and (3) dredging (sand and gravel are recovered from public waterways such as lakes, rivers, and estuaries). The breakdown in the United States is as follows: 50 percent by dry pit; 30 to 40 percent by wet pit; and 10 to 20 percent by dredging of public waterways (51).

Although the extracted raw material can be processed by various methods, most are similar in that they involve some form of transporting, screening, washing, crushing, blending, and stockpiling. The most common extraction/processing methods are illustrated in Figure 13a and 13b and described in the following paragraphs.

Dry Process--

After a site is cleared and overburden is removed, sand and gravel are extracted from the deposit by front-end loaders, power shovels, or scrapers. The raw ore is then transported to a processing facility by conveyor or truck.

In the initial step of dry beneficiation sand is separated from gravel via inclined vibrating screens. The sand and gravel are then sized as they pass through a number of screens of varying mesh sizes. Material too large to pass through the screens is crushed and resized.

Wet Process--

The site is cleared, overburden is pushed back, and the pit is flooded. The sand and gravel are then recovered by dragline, suction dredge, or bucket dredge. The raw material is transported to a processing facility by conveyor belts, slurry lines, trucks, or barges. There the sand and gravel are first dumped into a hopper or coarse ore bin covered by a grizzly, where the raw material is subjected to primary and secondary screening and crushing (52). Primary crushing reduces the particle size to less than 5 centimeters and secondary crushing reduces it to less than 3-3/4 centimeters (52). Primary crushing is performed by cone or gyratory crushers and secondary crushing by roll crushers. Screens can be horizontal or sloped, single or multi-deck. They also may be either vibrating or revolving, and they are frequently heated to prevent clogging. Wash water is sprayed on the product throughout the screening/crushing operation. The material is sometimes washed further by passing it through log washers or rotary scrubbers.

Following initial screening, crushing, and washing, the material is fed to a battery of screens for product sizing. The different sizes of gravel are discharged from these screens into bins or conveyed to stockpiles or sometimes to crushers and other screens for further processing. The sand fraction coming off of the battery of screens is fed to classifiers, separatory cones, or hydroseparators for additional washing, sizing, and water removal. At most facilities, two size categories of sand are stockpiled: coarse (1 to 0 centimeter) and fine (1/3 to 0 centimeter) (52). The sized sand and gravel are then ready for various degrees of blending as required for use in building construction or concrete and bituminous paving.

At several facilities heavymedia separation (HMS) is used prior to wet processing to remove very fine deleterious materials

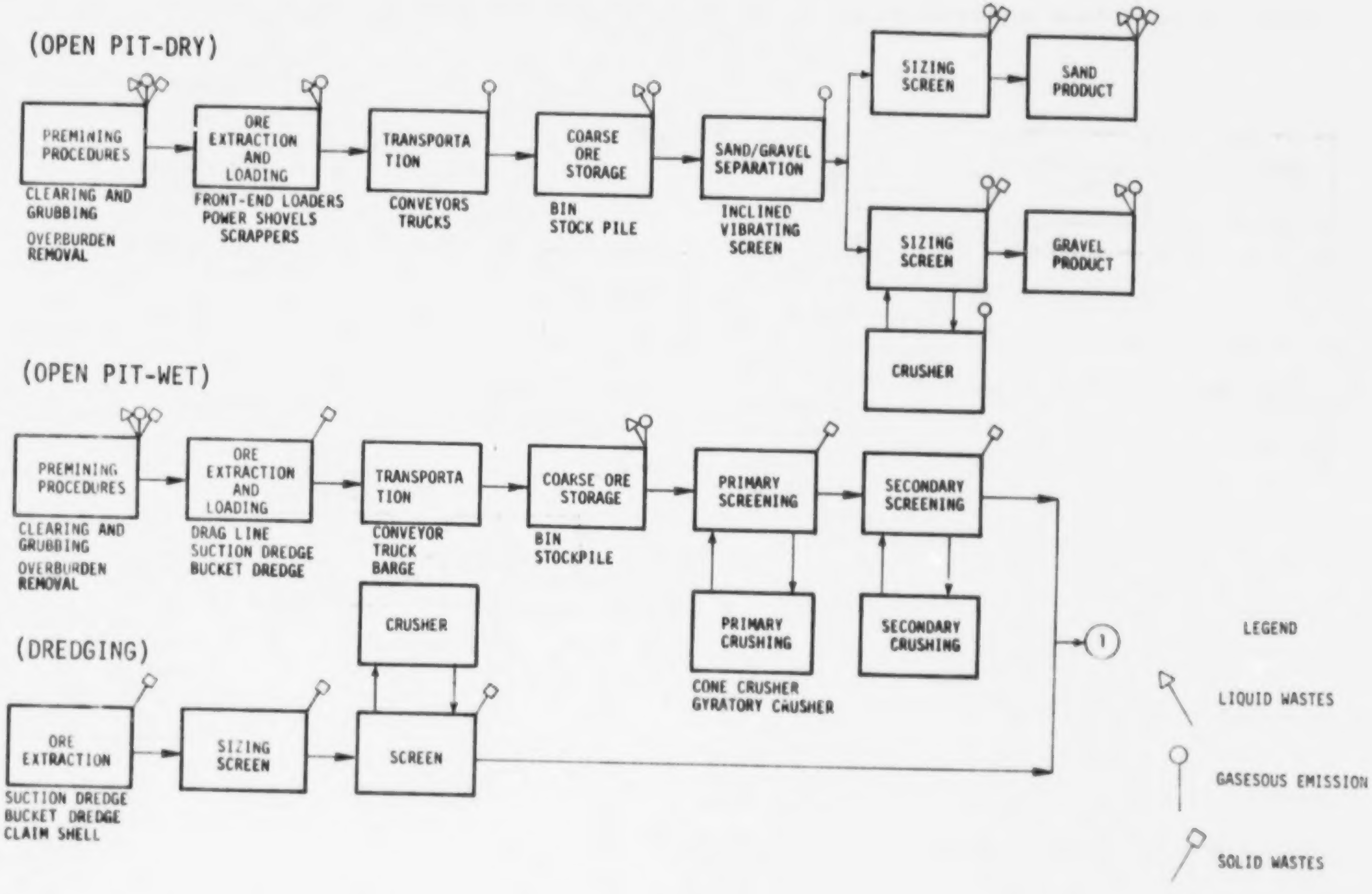
(OPEN PIT-DRY)
PREMINING PROCEDURES
CLEARING AND GRUBBING
OVERBURDEN REMOVAL
ORE EXTRACTION AND LOADING
FRONT-END LOADERS
POWER SHOVELS
SCRAPPERS
TRANSPORTA TION
CONVEYORS
TRUCKS
COARSE ORE STORAGE
BIN
STOCK PILE
SAND/GRAVEL SEPARATION
INCLINED VIBRATING SCREEN
SIZING SCREEN
SAND PRODUCT
SIZING SCREEN
GRAVEL PRODUCT
CRUSHER
(OPEN PIT-WET)
PREMINING PROCEDURES
CLEARING AND GRUBBING
OVERBURDEN REMOVAL
ORE EXTRACTION AND LOADING
DRAG LINE
SUCTION DREDGE
BUCKET DREDGE
TRANSPORTA TION
CONVEYOR
TRUCK
BARGE
COARSE ORE STORAGE
BIN
STOCKPILE
PRIMARY SCREENING
PRIMARY CRUSHING
CONE CRUSHER
GYRATORY CRUSHER
SECONDARY SCREENING
SECONDARY CRUSHING
1
(DREDGING)
ORE EXTRACTION
SUCTION DREDGE
BUCKET DREDGE
CLAIM SHELL
SIZING SCREEN
CRUSHER
SCREEN
LEGEND
LIQUID WASTES
GASESOUS EMISSION
SOLID WASTES

Figure 13a. Mining and beneficiating of construction sand and gravel.

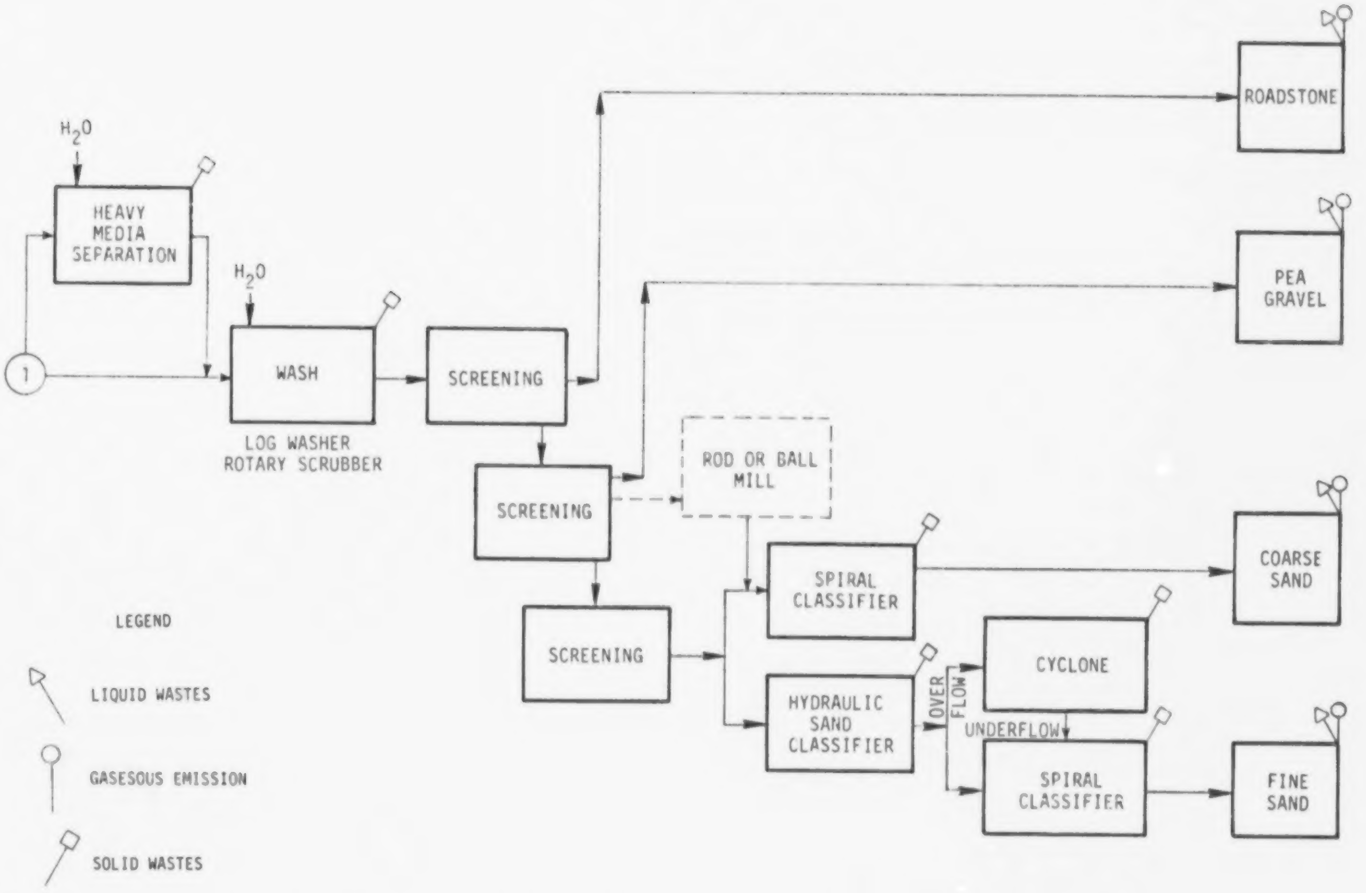
H_2O
HEAVY MEDIA SEPARATION
1
H_2O
WASH
LOG WASHER ROTARY SCRUBBER
SCREENING
SCREENING
SCREENING
ROD OR BALL MILL
SPIRAL CLASSIFIER
HYDRAULIC SAND CLASSIFIER
OVER FLOW
CYCLONE
UNDERFLOW
SPIRAL CLASSIFIER
ROADSTONE
PEA GRAVEL
COARSE SAND
FINE SAND
LEGEND
LIQUID WASTES
GASESOUS EMISSION
SOLID WASTES

Figure 13b. Mining and beneficiating of construction sand and gravel.

that would not be washed away by normal scrubbing and screening operations. These fine particles include soft fragments, thin and friable particles, shale, argillaceous sandstones and limes, porous and unsound cherts, coated particles, coal, lignite and other low-density impurities (39). HMS (sink-float) removes the deleterious materials as a result of the different specific gravities of the particles involved. The sand and gravel product (sink fraction) and the impurities (float fraction) pass over separate screens, where the heavy-media materials are removed by separation and recycled. The impurities are usually disposed of on site and the product is transported to a wet processing facility for further washing, crushing, and sizing.

Dredging with On Land/On Board Processing--

Raw material is extracted from public waterways using floating, movable dredges, which excavate the bottom sand and gravel deposit by one of the following methods: a suction dredge with or without cutter-heads, a clamshell bucket, or a bucket-ladder dredge. After the sand and gravel have been brought onto the dredge, they can be transported directly to an on-land processing facility (via barges or a slurry line) or be partially or completely processed on board the dredge. When transported to an on-land facility, the raw material is processed in a manner similar to that described under Wet Process. Partial on-board processing involves primary sizing and/or crushing performed by vibrating or rotary screens and cone or gyratory crushers. Oversize boulders are returned to the water. Following these initial steps the ore usually is transported to on-land facilities for additional processing; however, the product sometimes is ready for sale following on-board processing. When raw material is processed completely on board, it is treated in a manner similar to that described earlier under Wet Process. Following the on-board beneficiation, sized sand and gravel are loaded onto tow-barges and delivered to the user or stockpiled on land.

Waste Streams

Various atmospheric, liquid, and solid waste materials result from sand and gravel extraction and processing. These waste streams are shown in Table 11 and discussed in detail in the following paragraphs.

Air Emissions--

Particulate emission sources in the sand and gravel industry parallel those in the crushed stone industry. They may be fugitive or process in origin. Process sources include crushers, screens, conveyors, and loading mills (25). Fugitive sources include haul roads, stockpiles, and open loading areas.

TABLE 11. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF CONSTRUCTION SAND AND GRAVEL

	Air			Liquid			Solid		
Process	Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Open pit (dry)	Processing equipment	Particulates	0.05 kg/Mg of product[a]	Incidental water[e]	TSS[f]	N.A.	Premining procedures	Overburden (soil & rock)	N.A.
	Stockpiles	Fugitive particulates	0.06 to 2.6 kg/Mg of product[b]				Crushing/ screening	Dry tailings	N.A.
	Vehicle transport	Fugitive particulates	0.56 to 2.13 gram/vehicle-meter[c]						
	Other fugitive sources[d]	Fugitive particulates	N.A.						
Open pit (wet)	Processing equipment	Particulates	0.05 kg/Mg of product[a]	Wet processing[g]	Process wastewater	50 to 480 kg/Mg of raw material[h]	Premining procedures	Overburden (soil & rock)	N.A.
	Stockpiles	Fugitive particulates	0.06 to 2.6 kg/Mg of product[b]	Incidental water[c]	TSS[f]	N.A.			
	Vehicle transport	Fugitive particulates	0.56 to 2.13 gram/vehicle-meter[c]	Settling pond discharge	TSS[f]	0.006 to 0.26 kg/Mg of product	Dewatering devices and settling ponds	Sludges[m]	N.A.
	Other fugitive sources[d]	Fugitive particulates	N.A.	Percolation[i]	TSS[f]	N.A.			
Dredging (on-land processing)	Processing equipment	Particulates	0.05 kg/Mg of product[a]	Wet processing[g]	Process wastewater	60 to 40 kg/Mg of feed[h]			
	Stockpiles	Fugitive particulates	0.06 to 2.6 kg/Mg of product[b]	Settling pond discharge	TSS[f]	0.10 to 22.0 kg/Mg of product[h]	Dewatering devices and settling ponds	Sludges[m]	N.A.
	Vehicle transport	Fugitive particulates	0.56 to 2.13 gram/vehicle-meter[c]	Settling pond percolation[i]	TSS[f]	N.A.			
	Other fugitive sources[d]	Fugitive particulate	N.A.	Dredge disturbance[k]	TSS[f]	180 to 460 kg/Mg of raw material[h]			
Dredging (on-board processing)				Dredge discharge	TSS[f]	325 kg/Mg of raw material[l]			
				Dredge disturbance[k]	TSS[f]	N.A.			

[a] Ref. 53. This value is an overall estimate of source particulate emissions and includes operations such as conveying screening, and crushing.

[b] Ref. 55. These emission factors are based on PE values of 150 and 25, respectively. See text for explanation.

[c] Ref. 56.

[d] Other fugitive sources could include overburden removal, transfer and conveying, truck loading, and abandoned waste disposal areas. For explanation of emission factors for these sources see text.

[e] Incidental water refers to wastewater generated by various miscellaneous sources such as mine pumpout, surface runoff, noncontact cooling water and water used for dust supression.

[f] TSS = total suspended solids.

[g] Wet processing refers to operations such as washing, desliming, heavy media separation, etc.

[h] Ref. 39. This range is a result of monitoring the wastestreams at several selected sand and gravel operations.

[i] Percolation refers to water that escapes from the bottom of settling ponds.

[j] Dredge discharge refers to the waste materials separated from sand and gravel by on-board processing. The on-board processing may involve partial or complete beneficiation.

[k] Dredge disturbance refers to the agitation of the bottoms of lakes, rivers, or estuaries due to the action of dredging assemblies.

[l] Ref. 39. This value is an estimate assuming that 32.5 percent of the total material being dredged is discarded back into the water being worked.

[m] Sludge refers to the suspended solids removed from process wastewater by mechanical devices or settling ponds.

N.A. Not available.

Of the three basic types of sand and gravel facilities [open-pit (dry), open-pit (wet), and public waterway dredging with on-board/on-land processing], open-pit (dry) operations generate the most particulate emissions because the moisture content of the raw material is lower and no water is used in the beneficiation process. Particulate emissions emanate from both process and fugitive sources.

Processing operations at open-pit (wet) facilities normally do not produce any particulate emissions because of the high moisture content of the material being processed. Most particulate emissions come from fugitive sources.

Those facilities that practice dredging with complete on-board processing experience few problems with particulate emissions because the moisture content of the material is always very high.

Little information is available on emission factors from sand and gravel plants. One report lists overall emissions as 0.03 kilograms per megagram of material through the facility (53). The sources of dust are listed as the secondary and reducing crushers and the elevator boot on the "dry side." Seventy-five percent of the dust is estimated to come from the crushers. More recently, Midwest Research Institute (MRI) provided an estimated overall emission factor of 0.05 kilograms of dust per megagram of product (53). This factor is based on process sources only and does not include fugitive sources such as stockpiles or haul roads.

Sand and gravel particulate emissions data from fugitive sources are even more scarce than for process sources, however, emission factors are available for a few sources, such as stockpiles and vehicle transport. One state agency estimates emissions from stockpiles to be approximately 0.1 percent of finished product for sand and 0.5 percent for gravel (54). More recently, MRI compiled and evaluated data for emissions from aggregate storage piles (55). Based on the results of this study, they developed an empirical expression for estimating fugitive emissions from aggregate stockpiles:

$$E = \frac{0.165}{\left(\frac{PE}{100}\right)^2}$$

where: E = Emission factor, kilograms per megagram placed in storage
PE = Thornthwaite's Precipitation-Evaporation Index

Based on PE values of 25 and 150 (which are representative of a broad range of areas where sand and gravel are extracted), stockpile emission rates would be equal to 2.6 and 0.06 kilograms per megagram of product placed in storage, respectively.

Vehicle transport is another contributor to the total particulate emissions emanating from sand and gravel operations, and often is the major source of particulates. The emission factor for respirable particulate emissions from transport of sand and gravel is 0.56 gram per vehicle-meter, with a range of 0.14 to 2.13 grams per vehicle-meter (56). Even though these values represent emissions resulting from the transport of the product from finished stockpiles to the consumer, they are likely also to be representative of emissions generated by vehicular transport within the boundries of sand and gravel plants.

Other sources of fugitive emissions associated with the sand and gravel industry include overburden removal, transfer and conveying and abandoned or dry tailings dumps. Although data on emissions from these sources are not available for the sand and gravel industry, they are for other industries (crushed stone, copper, and phosphate) whose operations parallel those in the sand and gravel industry. Therefore, fugitive particulate emissions data for these industries provide the best available bases for estimating fugitive emissions for the sand and gravel industry.

Although limited data are available on the characteristics of particulate emissions from sand and gravel plants, it is feasible to assume they would be similar to the characteristics of the raw material being handled. Although sand and gravel consist primarily of silica, other constituents are sometimes present such as limestone or combined silica in the form of feldspar, mica, and other mineral silicates and aluminosilicates (2). Free silica is the only potentially hazardous constituent in emitted particulates. The average free silica content of emissions resulting from vehicular transport is 14 percent, with a range of 1.4 to 47 percent by weight (56).

Liquid Waste Streams--

Since processing water is not used at dry open-pit operations, no major aqueous waste streams are associated with these facilities. Dry processing produces some incidental wastewater, which includes mine pumpout, surface runoff, noncontact cooling water, and water used for dust suspression (39). These effluents are usually discharged directly to the watershed.

Incidental water may also be a source of liquid waste at wet open-pit operations. At most wet facilities incidental water is discharged to a settling pond rather than to the watershed. The major liquid waste associated with wet facilities is process wastewater. The wastewater may be discharged from process operations directly to receiving waters, or it may be discharged through constructed tailings ponds or extraction pits (active or abandoned working pits). The amount of process wastewater generated as a result of wet beneficiation of sands and gravel ranges between 50 and 480 kilograms per megagram of raw material processed (based on monitoring at five separate facilities (39). Process wastewater at many operations is recycled back to the process after treatment; however, some facilities discharge treated wastewater. Treated wastewater discharges were monitored at several plants and ranged between 0.006 and 0.26 kilograms TSS per megagram of product (39). An additional source of aqueous waste at wet facilities is water that escapes from settling ponds by percolation. The quantity of wastewater from this source has not been measured.

Plants that combine dredging with on-land processing operations generate aqueous waste from their land-based processing facilities that is similar to effluents from wet plants. These facilities also generate processing wastes at the dredge itself as a result of partial on-board processing. The following is a tabulation of these waste loads at several operations (39):

Operation no.	Waste generated at dredge, kg/Mg of feed	Waste generated at land facility, kg/Mg of feed
1	460	100
2	None	400
3	None	150
4	None	110
5	None	120
6	250	60
7	180	120

Process wastewater at land-based facilities is normally treated and recycled. The total suspended solids level of recycled wastewater measured at four separate operations ranged between 50 and 400 megagrams per liter (39). Two facilities are known to discharge treated wastewater. The TSS level of discharge is 22 kilograms per megagram of product at one plant and 0.10 at the other.

Effluents from dredging units with complete on-board processing contain essentially the same high suspended solids concentrations as those generated by land-based operations, and additional solids are placed into suspension by the action of the recovery assemblies. No information is available for effluents from dredging operations with complete on-board processing. It is estimated though, that approximately 25 percent of the total volume of material being dredged plus 10 percent of the material going to processing is discarded back into the body of water being dredged (39). The total discharge resulting from on-board processing, based on these percentages, would be equal to 325 kilograms per megagram (32.5 percent) of initial feed. No estimate is made of the suspended solids introduced into public waterways by the action of dredging assemblies.

Although aqueous wastes discharged from sand and gravel operations do not contain any toxic materials, they can be very high in total suspended solids. Since the characteristics of the suspended materials relate to the characteristics of the raw material being extracted and processed, discharges are expected to contain silica, limestone, feldspar, mica, and other mineral silicates and aluminosilicates.

Solid Wastes--

Solid wastes generated by mining and beneficiation of sand and gravel may include overburden, oversized rock removed during initial waste/raw material separation, and tailings resulting from dry processing operations. Solids removed from process wastewaters by mechanical dewatering devices and/or settling ponds also add to the solid waste when plants have operations such as scrubbing, dewatering, desliming, and heavy media separation. No data were found on the amounts of solid waste generated by these sources.

Control Technology

Many of the larger, permanent sand and gravel operations greatly reduce their waste problems by applying extensive control technology. Some plants are limited in their ability to treat wastes by the best available methods because, for example, they do not have sufficient land for settling ponds. Other plants, particularly those that operate on intermittent or part-time schedules, practice little or no waste control.

The best control technology now available is discussed in the following paragraphs.

Air Emission Control--

Particulate emissions from both process sources (screening, crushing, transferring, etc.) and fugitive sources (haul roads, stockpiles, waste dumps, etc.) are the major atmospheric wastes of concern at sand and gravel plants. Emission control methodology used to reduce these particulates include dry collection systems, wet dust suppression, wind reduction, and various combinations thereof.

Dry collection systems--Particulate emissions generated by process operations can be controlled by capturing and exhausting emissions to a collection device. The most effective dust collection device in the sand and gravel industry is the fabric filter or baghouse. Mechanical shaker-type collectors which require periodic shutdown for cleaning, are the most common. Baghouses give greater than 99 percent efficiency, even on submicrometer particle sizes (38). Cyclones and low-energy scrubbers, which are sometimes used, demonstrate efficiencies of 95 to 99 percent for coarse particles (+40 micrometer), but their efficiencies are usually less than 85 percent for medium and fine particles (-20 micrometer) (38).

Wet dust suppression--Wet dust suppression techniques, designed to prevent particulate matter from becoming airborne, may be used to control both process and fugitive sources. Dust emissions are controlled by spraying moisture (water or water plus a wetting agent) on critical dust-producing points in the process flow. One California plant, which operates a wetting system to control particulate emissions from both process and fugitive sources, mixes a wetting agent called compound MR with water at a ratio of 1 cubic meter of solution to 100 cubic meters of water (57). Approximately 4 cubic meters of this mixture is applied to every 1000 megagrams of crushed material by means of sprays at the top and bottom of the secondary cone crushers. The system has the advantage of a carry-over effect in subsequent transfer, screening, and storage operations. Also, it does not blind the screens because it operates at a level of 1/2 to 1 percent total moisture.

Wet dust suppression systems have been used extensively for many years to control dust from fugitive sources. Applying plain water on haul roads has been a common practice. Although water application has also been used to control dust from overburden removal, stockpiles, and waste disposal, such practice is not widespread. Among the reasons many operations do not use plain water for dust control is its ultimate high cost. Initial cost is low, but control is temporary and the need for frequent applications adds materially to the cost. For this reason, many sand and gravel operators are turning to chemical wetting agents, which provide better wetting of fines and longer retention of the moisture film. Wetting aids can be applied directly to the surface being controlled or they can be worked into the material being treated. Chemical treatment programs reduce total particulate emissions from fugitive sources by up to 90 percent, whereas watering provides a dust-control efficiency of only 50 percent.

Reduction of wind speed--Wind contributes significantly to all particulate dust sources at a sand and gravel operations, by erosion of the exposed surfaces of stockpiles, tailings piles, and reclaimed areas, and by direct transport of the dust generated by other extraction and processing operations. Windbreaks, enclosures or coverings for the sources, and planting of tall grasses or grains on or adjacent to exposed surfaces can reduce surface wind speed and result in control efficiencies of between 65 and 90 percent.

Control method combinations--Some sand and gravel facilities use a combination of several of the control methods mentioned. For example, wet dust suppression techniques are used to prevent emissions at primary crushers, screens, transfer points, and crusher inlets, and dry collection is applied to control emissions at the discharge of secondary and tertiary crushers, where new dry surfaces and fine particulates are formed.

Some operations control fugitive dust from abandoned tailings dumps by combinations of watering, chemical stabilizers, and vegetation cover. These combination methods often achieve 90 to 95 percent efficiency (58).

Liquid Waste Control--

Sources of liquid waste at sand and gravel operations include incidental water (surface runoff, mine pumpout, non-contact cooling water, etc.), process wastewater, settling pond discharge, percolation from settling basins, and dredging of public waterways. Many facilities discharge incidental wastewater directly to the watershed without prior treatment. Other plants combine incidental wastewater with process wastewater, then pump the wastes to treatment. Settling ponds are the predominant method for treating wastewater. The ponding method requires the construction of new ponds or utilization of active/ abandoned extraction pits. The size, configuration, and number of treatment ponds needed depend on such factors as total suspended solids content of the inflow, retention time, land availability, and climate. Some plants facilitate settling and minimize the size of settling ponds by introducing settling aids into the water.

Some operations utilize mechanical devices such as dewatering screws, cyclones, and classifiers followed by settling basins to treat process wastewater. The mechanical devices remove a large portion of the fine sands (+200 mesh) and the settling ponds remove the colloidal material (-200 mesh). Mechanical devices decrease the solids load going to the pond and expedite the settling of colloidal material in the pond, thereby decreasing the frequency of pond cleanout. Many operations that combine mechanical devices with settling ponds for process wastewater treatment achieve a final pond discharge of high enough quality (<200 micrograms per liter of total suspended solids) to be recycled and used as process water.

Effluents from settling ponds are discharged to abandoned or active excavation pits, recycled, or released to the watershed. Discharge may be intermittent (only during heavy rains) or continuous, depending on the size of the operation, degree of processing, and climatic conditions of the area. Effluents released to the watershed usually do not receive any treatment after they leave the settling ponds, and at some facilities (particularly intermittent and temporary operations) process wastewater is discharged directly to navigable waters without any treatment.

Percolation from settling basins occurs at some sand and gravel operations. The best control method is to locate the settling basin over impervious bedrock whenever possible.

Dredging of public waterways introduces large amounts of suspended solids into the water. The raw wastes result from the discharge of process wastewater (generated by on-board processing) and disturbance of the substrate by the action of the dredging assemblies. Efforts to control these sediments include diking, silt curtains, and bubble barriers, none of which has been totally successful (51).

Solid Waste Control--

Solid wastes associated with the sand and gravel industry include overburden, oversized rock, and dry waste fines (tailings from dry open-pit operations). The removal of waste fines from process wastewater by mechanical devices and/or settling ponds results in additional solid waste (sludges) at wet sand and gravel operations.

Overburden, oversized rock, and dry waste fines are stockpiled at some operations and used to reshape the contour of the land during reclamation procedures. At other facilities these wastes are disposed of in active/abandoned pits or in any low area that will take fill. If adequate space is not available for disposal on site, this material is hauled to an off-site dump. In some instances, it is transported away from the site and sold.

The ultimate disposal of sand and colloidal fines removed from process wastewater is a major problem. Colloidal fines are more difficult to deal with than sand fines because they are harder to dewater. Many operations have available land for disposal of waste fines. Some use previously mined areas or obsolete sedimentation ponds, or disperse the sludge to open land areas for drying. At operations where sufficient land is available, exhausted tailings ponds are abandoned and new ones constructed. At facilities where land for settling ponds is limited, it is necessary to extract as much marketable material as possible. Classifiers and/or cyclones that remove product material down to the 100-mesh range help to minimize solid waste problems. Sometimes solid waste generated by these devices is transported to off-site dumps, but if the fines are of top soil or fill dirt quality, they can be readily and profitably sold in the immediate area. The fines can also be mixed with coarser material to facilitate drying and enhance the quality of the finished product. Some operators have added organic debris such as leaves and commercial fertilizers to waste fines to yield a profitable product. Waste fines have also been used to produce building bricks, an activity which may increase proportionately with the demand for construction materials, especially since sand and gravel operations are located near metropolitan areas.

Conclusions and Recommendations

Most of the larger sand and gravel operations are maintaining air, liquid, and solid wastes at acceptable levels by applying state-of-the-art control technology. Particulate emissions from process sources are being minimized by applying well-established control techniques (watering, wetting agents, exhaust and collection systems, etc.). Although technology for the control of fugitive emissions has not advanced to the level of that for source emissions, it is improving rapidly. Process wastewater and incidental wastewater are controlled by mechanical devices followed by settling ponds. At some operations, pond effluent is completely recycled resulting in zero discharge. Solid wastes (colloidal fines removed from settling ponds) are being land spread at facilities with sufficient area or recovered as useful by-products.

Even though many operations are maintaining good pollution control programs, some environmental problems still persist. These problems and related research and development needs are discussed below.

A major problem that faces the sand and gravel industry is the dewatering of settling pond sludge, which consists of colloidal fines (-200 mesh). Reportedly, no technology is available for economical dewatering of these silts. Efforts to use various mechanical devices such as vacuum filters and hydraulic cones have been generally unsuccessful. Vacuum filtration is economically prohibitive because of the enormous quantities of sludge that must be treated. Hydraulic cones effectively remove fine sands (+200 mesh), but they are not efficient enough to remove small colloidal particles. Some operators are now trying to remove silts with centrifuges, which have been used successfully for dewatering of coal mine slimes. This may be a practical solution to the problem. Research is needed to identify the properties of these colloidal particles to determine why it is so difficult to dewater them. Dewatering devices such as vacuum filters and and hydraulic cones have been partially effective;

however, additional laboratory and field research is needed. Laboratory research is also needed to determine the effectiveness of centrifuges, and a pilot plant should be developed if the laboratory tests are promising.

Another serious problem involves the ultimate disposal of dewatered waste fines. Where sufficient land is available, waste fines are land-spread on site, thereby alleviating drying and disposal problems by a single method of control. Nonetheless, these deposits can result in fugitive dust if methods of suppression are not employed. At operations where sufficient area is not available for this approach, waste fines are either hauled to off-site dumps or recovered as a by-product of some type. If the material being recovered is of topsoil quality, it can be sold directly to farmers and land-spread without any additives. Some operators mix their sediments with materials such as leaves, municipal sludge, and commercial fertilizers to facilitate drying and to enhance the quality of the product. Additional research is needed to determine how effective waste fines (with or without additives), are as soil builders or fertilizers. Research is also needed to identify other uses. Construction materials such as building bricks and road base fill should be investigated as potential by-products. The biggest problem involves finding an accessible market for by-products in the immediate vicinity of the sand and gravel plant. A survey should be made of industry to determine what markets are available and where they are located.

Numerous sand and gravel producers operate on a part-time or temporary basis. These are usually dry-pit operations and effluents from process wastewaters are not a major problem; however, considerable discharge can result from storm runoff and pit pumpout. It is estimated that storm runoff from one of these temporary operations is capable of producing a silt load exceeding the yearly output of a well-managed permanent sand and gravel plant (51). It should be noted also that silt discharge can continue after an operation has been abandoned. Research is needed to determine the practicality of constructing diversion ditches and/or retaining dikes to contain and control runoff at these temporary facilities.

Seepage and percolation from settling basins is a problem that can cause surface and ground water to become contaminated at some plants. The nature and extent of seepage/percolation from settling ponds should be evaluated, followed by research relating to possible preventive measures (e.g., synthetic or earthen liners).

Dredging in public waterways introduces large amounts of suspended solids into these waters, thereby posing an environmental threat. Research should be initiated to determine effective and economical means of removing or containing suspended solids generated from dredging operations. Various devices that have been partially effective but need additional research include dikes, silt curtains, and bubble barriers.

INDUSTRIAL SAND

Industry Description

Industrial sands differ from construction sands in that they contain little or no impurities. Industrial sands are silicate minerals that have been segregated and refined by natural processes into nearly monomineralic deposits. Because of their high degree of purity, they have special and somewhat restricted uses (39). Most often, industrial sands occur naturally in sandstone, conglomerate quartzite, quartz mica schist, or massive igneous quartz. These ores are refined to produce a sand of suitable composition and texture. Industrial sands are recovered also from quartzose sand and gravel deposits, which can be exploited and used with very little preparation and expense.

Although industrial sands amounted to only about 4.5 percent of total sand and gravel production in 1974, they represented 10 percent of the total value. (Present and projected production statistics for silica sands appear in Section 1 of this report.)

Industrial sands are vital to glass manufacture, ferrous and nonferrous foundry operations, some chemical and metallurgical processes, and as extenders in manufactured products (2). Glass sands must be free from iron oxide and other impurities. Molding sands for foundry use usually contain clay as the bonding agent. Other industrial classifications include abrasive sand for sandblasting, sawing, and grinding; filter sand for treating water supplies, and ground sand for filler in paint, asphalt, tile, plastic, and rubber.

Nearly half of the states in the Union are involved in the recovery of industrial sands. No one state produces all of the various types of silica sands in use today, although a single state may be noted for several varieties. Table 12 lists some of the major producing states of industrial sands by end-use (2).

Some materials or substitutes compete with silica sands, and will probably have some impact on the future of the industrial sand industry. For example, zircon and mullite are more refactory than silica sand and are used in foundry molds where temperature or other conditions exceed the limits of silica molding sand. Crushed garnet, ceramic materials, and ion exchange resins

TABLE 12. MAJOR PRODUCING STATES OF INDUSTRIAL SANDS

End-Use	Location of Deposits
Blasting sand	Ohio, Illinois, Pennsylvania, West Virginia, New Jersey
Glass-melting and chemical sands	West Virginia, Pennsylvania, Virginia, Illinois, Missouri
Metallurgical pebble	Ohio, Tennessee, New York, Pennsylvania, North Carolina
Refractory sands:	
Core sand	Illinois, Ohio, Michigan, West Virginia, Pennsylvania
Ganister mix	California, Illinois, Ohio, Massachusetts, Wisconsin
Naturally bonded molding sand	New York, New Jersey, Ohio
Processed molding sand	Illinois, New Jersey, Pennsylvania, Ohio, West Virginia
Refractory pebble	Ohio, Indiana, Pennsylvania, Maryland Wisconsin

Source: Ref. 2.

are suitable substitutes for filter sand. Fused alumina, silicon carbide, garnet, corundum, emery, and diamond represent alternate abrasives.

Process Description

Industrial sands may be obtained from open pits (wet or dry), beach deposits, or sandstone quarries (39). Prior to extraction, mine sites are cleared and grubbed, overburden is removed, and working roads are constructed. Raw material from dry pits, sandstone quarries, and beach deposits is extracted by front-end loaders, power shovels, or scrappers. Ore extraction at wet pits is usually accomplished with hydraulic dredges. Raw material is transported to processing facilities (some on site and others located away from the mine site) by conveyor belts, trucks, or slurry lines. Processing typically consists of some combination of scalping/screening, crushing, scrubbing, dewatering, sizing, and drying. Some facilities have additional operations such as rod milling, flotation, and magnetic separation. The specific type and amount of processing at a facility is controlled by the quantity of impurities in the deposit, grain size of the material, and specifications of the user. Glass sand, for example, must be of higher purity than foundry sand and therefore requires more processing. The various methods of processing silica sands are illustrated in Figure 14 and discussed in more detail in the following paragraphs.

Ore recovered from sandstone quarries is reduced to a size of about 2.54 centimeters by a jaw crusher, then further reduced to natural sand grain size by wet rod milling (28). Generally, one-pass treatment through the crusher and mill is sufficient; however, at large scale operations two-stage crushing and milling may be practiced. Reduced ore is passed over a 20-mesh screen; oversize goes to waste or back to the mill and minus-20-mesh material goes to further treatment.

Silica sand recovered from dry open pits is generally loaded into trucks and transported dry to a mill receiving bin. It is then fed onto a vibrating screen along with sufficient water to wash the sand through a 20-mesh screen cloth. The material is further washed by water sprays, with oversize going to waste or other use. The minus-20-mesh material (which may or may not be dried first) goes to product storage or to further processing.

Sand that is recovered from deposits below the water table (wet pits or beach sands) is usually extracted by hydraulic dredges, then pumped to a 20-mesh vibrating screen. The oversize fraction goes to waste and the material passing through the screen (minus-20-mesh) goes to either product storage or further treatment.

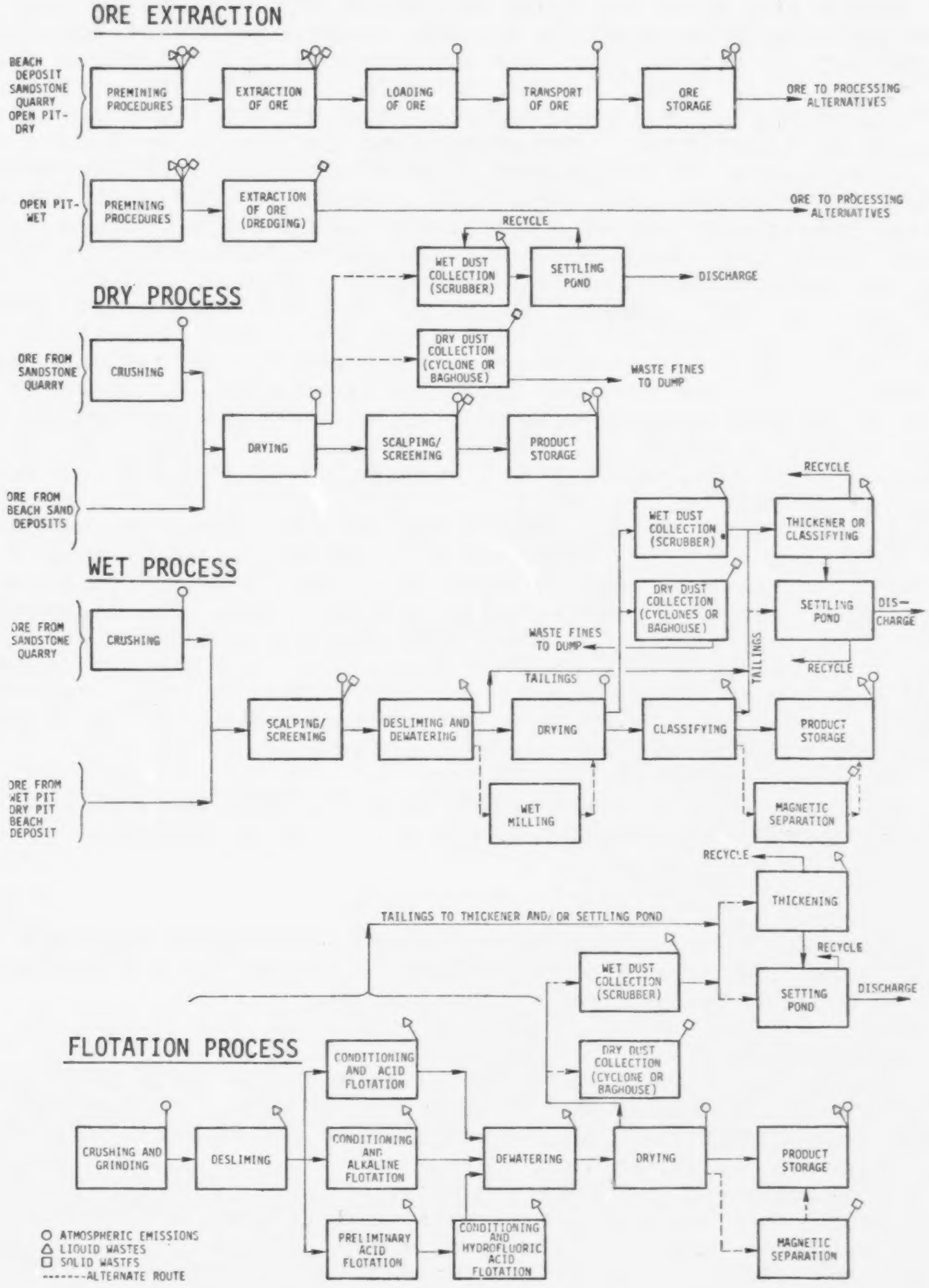
ORE EXTRACTION
BEACH DEPOSIT SANDSTONE QUARRY OPEN PIT-DRY
PREMINING PROCEDURES
EXTRACTION OF ORE
LOADING OF ORE
TRANSPORT OF ORE
ORE STORAGE
ORE TO PROCESSING ALTERNATIVES
OPEN PIT-WET
PREMINING PROCEDURES
EXTRACTION OF ORE (DREDGING)
ORE TO PROCESSING ALTERNATIVES
DRY PROCESS
RECYCLE
WET DUST COLLECTION (SCRUBBER)
SETTLING POND
DISCHARGE
DRY DUST COLLECTION (CYCLONE OR BAGHOUSE)
WASTE FINES TO DUMP
ORE FROM SANDSTONE QUARRY
CRUSHING
DRYING
SCALPING/SCREENING
PRODUCT STORAGE
ORE FROM BEACH SAND DEPOSITS
WET PROCESS
RECYCLE
WET DUST COLLECTION (SCRUBBER)
THICKENER OR CLASSIFYING
DRY DUST COLLECTION (CYCLONES OR BAGHOUSE)
SETTLING POND
DIS-CHARGE
WASTE FINES TO DUMP
TAILINGS
TAILINGS
RECYCLE
ORE FROM SANDSTONE QUARRY
CRUSHING
SCALPING/SCREENING
DESLIMING AND DEWATERING
DRYING
CLASSIFYING
PRODUCT STORAGE
WET MILLING
MAGNETIC SEPARATION
ORE FROM WET PIT DRY PIT BEACH DEPOSIT
RECYCLE
THICKENING
TAILINGS TO THICKENER AND/OR SETTLING POND
RECYCLE
WET DUST COLLECTION (SCRUBBER)
SETTING POND
DISCHARGE
DRY DUST COLLECTION (CYCLONE OR BAGHOUSE)
FLOTATION PROCESS
CONDITIONING AND ACID FLOTATION
CRUSHING AND GRINDING
DESLIMING
CONDITIONING AND ALKALINE FLOTATION
DEWATERING
DRYING
PRODUCT STORAGE
PRELIMINARY ACID FLOTATION
CONDITIONING AND HYDROFLUORIC ACID FLOTATION
MAGNETIC SEPARATION
○ ATMOSPHERIC EMISSIONS
△ LIQUID WASTES
☐ SOLID WASTES
-------ALTERNATE ROUTE

Figure 14. Mining and beneficiating of industrial sand.

After the sand has been recovered and treated by one of the three methods described, it is sent to primary classification for dewatering or classifying, by cyclones or by mechanical dewatering classifiers (drag, screw, or rake classifiers). After classification the sand is introduced into an attrition scrubber for removal of impurities. Scrubbed sand is then pumped to a second set of cyclones or mechanical classifiers for further removal of slimes. Sometimes the impurity content of the sand meets required specifications at this point, making the cyclone or classifier sand the final product. In other instances the sand may require additional cleaning because of a high concentration of difficult-to-treat impurities and/or high product specifications. Additional purification can be accomplished by two-stage attrition scrubbing with classification and slime removal between stages or by a variety of flotation techniques. Currently, the three flotation methods used are acid, alkaline, and hydroflouric acid flotation (39). In each method, raw material is first scrubbed according to standard procedures outlined above and then slurried to flotation cells, where various reagents are added. Flotation methods differ according to the types of conditioners and frothers added. Some of the reagents introduced include sulfuric acid, soda ash, sodium silicate, sulfonated oils, terpenes, and heavy alcohols. The silica sands are depressed and sink in the flotation cells, and the impurities are "floated" away. The sand recovered from the cells is pumped to a mechanical dewatering classifier for final dewatering, and is then either conveyed to a stock pile or drainage bin or is dried in a rotary dryer (oil or gas) and stockpiled.

At some facilities, final product purification and sizing are performed by magnetic separation and/or grinding.

Waste Streams

The air, liquid, and solid wastes associated with the industrial sand industry are summarized in Table 13 and discussed in more detail in the following paragraphs.

Air Emissions--

Mining and beneficiation of industrial sand produces both fugitive and process particulate emissions. Particulate emissions from industrial sand plants have had very little monitoring; however, some estimates are available. In 1975 the total annual release of particulates from industrial sand operations (all processes included) were reported to be 3.2×10^3 megagrams (this value is based on a total annual production of 2.68×10^6 megagrams) (56). Dryers are reportedly the major contributing source, but other process sources that generate significant amounts of particulates include crushing, screening, and milling operations. Particulate emissions from various fugitive sources

TABLE 13. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF INDUSTRIAL SAND

Air			Liquid			Solid		
Source	Pollutant	**Uncontrolled** emission rate	Source	Pollutant/ parameter	**Uncontrolled** discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal	Fugitive particulates	N.A.	Pit pumpout^{c}	TSS	N.A.	Overburden removal	Topsoil, subsoil, other strate	N.A.
Extraction or ore	Fugitive particulates	N.A.	Surface runoff^{d}	TSS	N.A.	Extraction of ore	Gangue	N.A.
Loading of ore	Fugitive particulates	N.A.	Wet scrubber discharge	TSS	5478 kg/day^{e}	Dry separating & classifying	Oversize and sand fines	N.A.
Transport of ore	Fugitive particulates	0.56 to 2.13 gram/ vehicle-meter^{a}	Washing^{f}	Clays	10-530 kg/Mg of raw material^{g}	Dewatering	Sludge (dewatered or settled clay and sand fines)	N.A.
Ore storage	Fugitive particulates	0.06 to 2.6 kg/Mg of product	Flotation^{f}	Flotation tailings	20-140 kg/Mg of raw material^{g}	Thickening		
Conveying, screening, & crushing	Particulates	0.05 kg/Mg of product^{a}	Flotation^{f}	Acid & flotation agents	0.055 kg/Mg of raw material^{h}	Clarifying		
Drying	Particulates	N.A.	Magnetic separation^{f}	Iron oxides	12 kg/Mg of raw material^{h}	Settling		
Product storage	Fugitive particulates	0.06 to 2.6 kg/Mg of product^{a}	Settling pond^{i}	Amount of treated wastewater discharged	6.83 m^3/Mg of product	Cyclones	Collected particulates	N.A.
Tailing dump	Fugitive particulates	N.A.	Washing^{f}	Clays	3 kg/Mg of raw material^{h}	Baghouses	Collected particulates	N.A.
Total industry (all processes)	Particulates	3.2 Gg/year^{b}	Flotation^{f}	Clays	3 kg/Mg of raw material^{h}			
			Settling pond^{i}	Amount of treated wastewater discharged	5.25 m^3/Mg of product^{h}			
			Settling pond^{i}	pH	7.8^{h}			
			Settling pond^{i}	TDS	209 mg/ℓ^{h}			
			Settling pond^{i}	TSS	5 mg/ℓ^{h}			
			Settling pond^{i}	Sulfate	9 mg/ℓ^{h}			

(Continued)

TABLE 13. (Continued)

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
			Settling pond^i	Oil & grease	<1.0 mg/ℓ^h			
			Settling pond^i	Iron	0.1 mg/ℓ^h			
			Washing^f	Clays	165 kg/Mg of raw material^h			
			Flotation^f	Flotation tailings	135 kg/Mg of raw material^h			
			Flotation^f	Acid & flotation agents	0.30 kg/Mg of raw material^h			
			Flotation^f	Floride (as hydrofluoric acid)	0.45 kg/Mg of raw material^h			
			Magnetic separation^f	Iron oxide	34 kg/Mg of raw material			
			Settling pond^i	Amount of treated wastewater discharged	0.91 kg/Mg of product			
			Settling pond^i	pH	7.0-7.8^h			
			Settling pond^i	TSS	5-47 mg/ℓ^h			
			Settling pond^i	Sulfate	27-330 mg/ℓ^h			
			Settling pond^i	Nitrate	0-9 mg/ℓ^h			
			Settling pond^i	Chloride	57-76 mg/ℓ^h			
				Floride	1.8-6.6 mg/ℓ^h			

[a] Emission estimate from construction sand and gravel industry. See Section 18.3.1.

[b] Ref. 52. Total annual emissions for entire industry including all processes.

[c] Facilities recovering silica sands from open pits (wet and dry) or from sandstone quarries have periodic pumpouts.

[d] Runoff may result from sources such as stockpiled overburden, extraction areas, ore and product storage piles, and abandoned tailings dumps.

[e] Ref. 2. Based on monitoring at one facility discharging scrubber water directly to the watershed with no prior treatment.

[f] Ref. 2. The liquid wastes associated with process sources are untreated (uncontrolled) process wastewaters which are combined and fed to either a settling pond or to a thickener followed by a settling pond.

[g] Ref. 2. The range in values is based on monitoring at four separated facilities.

[h] Ref. 2. This value is based on monitoring at one facility.

[i] Ref. 2. Discharges from settling ponds represent treated (controlled) waste streams.

N.A. - Not available.

(haul roads, conveyors, and stockpiles) also present periodic dust problems. Generally, however, fugitive dust problems are minimal because even at "dry" operations the surface moisture of the material is sufficient to prevent dusting.

No emission data specific to individual process and fugitive sources are available for the industrial sand industry. However, because of the similarity in materials, methods of recovery, and processing, atmospheric emissions of the industrial sand industry are based on those of the construction sand and gravel data, which are covered in the preceding section.

Liquid Wastes--

In sandstone quarries and dry pits, surface runoff and pit pumpout are the only sources of liquid wastes associated with the extraction of silica sands. These effluents are periodic and are highest during periods of heavy rainfall. Although typically high in suspended solids, they do not contain any potentially hazardous materials. Specific data concerning these effluents are not available.

Sources of liquid waste at facilities processing industrial sands include washing, desliming, dewatering, flotation, and wet milling operations. When wet scrubbers are used to control emissions from dryers, an additional wastewater stream is generated.

Table 13 presents data for a facility releasing wet scrubber water directly to the watershed with no prior treatment. Monitoring results indicate that the discharge contains 5478 kilograms TSS per day (39). At most facilities process wastewater and scrubber wastewater are treated and recirculated, but in some cases they are discharged after treatment. Discharge may be continuous or it may occur only during periods of heavy rainfall.

Table 13 describes in detail the untreated and treated (settling pond discharge) waste streams for several sand processing facilities, which use both scrubbing and flotation. The total quantity of wastewater going to treatment ranges between 60 and 730 kilograms per megagram of raw material (39). Treated wastewater discharge ranges between about 1 and 7 cubic meters per megagram of product. Untreated and treated waste streams consist of muds separated in the initial washing operations, iron oxides separated magnetically, impurities removed by flotation, and various flotation reagents.

Solid Wastes--

Overburden and gangue are both sources of solid waste at industrial sand operations. The quantities produced vary by site, depending on the type of deposit being mined (beach deposit, sandstone quarry, or wet pit) and the amount of impurities associated with the deposit. Other solid wastes include oversize and sand fines that are removed during dry separating and classifying operations. Dry dust collection of particulates from rotary dryers, by either cyclones or baghouses, also results in minor amounts of solid waste at some operations. Reports indicate that all these solid wastes are landfilled (39), but no data are available on quantities.

Wet processing and flotation result in a variety of solid wastes, including muds and waste fines removed during dewatering, thickening, clarifying, and settling operations. Although the wastes consist of impurities such as clays, iron oxides, and feldspar, they also contain some of the reagents (acids, caustics, oils, alcohols, etc.) used to remove the impurities. No data are available on the amounts of solid waste generated by these operations.

Control Technology

Control technology in the industrial sand industry is much the same as that used in the construction sand and gravel industry. The various air, liquid, and solid waste controls are described in the following paragraphs.

Air Emissions Control--

Fugitive dusts generated by operations such as overburden removal, ore extraction, loading/unloading, vehicular transport and conveying are controlled by wet suppression and or wind reduction techniques. Wet suppression consists of applying water or water plus a chemical wetting agent. Watering usually achieves a control efficiency of 50 percent, whereas water plus chemical additives can attain up to 90 percent.

The particulates released by process sources such as crushing and screening are generally minor since the material has enough surface moisture to prevent dusting (38). In some instances, particularly at dry operations, control devices are necessary. The usual method involves capturing and exhausting the particulates to a baghouse.

Dryers are the major source of particulate emissions at industrial sand operations.* Dust collection systems can be dry (cyclones and baghouses) or wet (scrubbers). Baghouses achieve an overall efficiency of up to 90 percent, whereas cyclones and low-energy scrubbers achieve 95 to 99 percent for coarse particles (+40 micrometer) but less than 85 percent for medium and fine particles (-20 micrometer) (58).

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*Telephone conversation between Jack Greber of PEDCo and Edward Davison, National Sand and Gravel Association, Silver Spring, Maryland. December 1976.

Liquid Waste Control--

Scrubber water, a major source of liquid waste at some industrial sand operations, generally is pumped to settling ponds, where suspended solids are settled, and then is decanted back to the scrubber, thereby resulting in no discharge. However, some facilities discharge scrubber water directly to the watershed with no prior treatment (39). In these cases, discharge points are typically not discrete, so use of National Pollutant Discharge System (NPDES) permits to enforce control is not practical.

Liquid wastes generated by scrubbing, desliming, dewatering, and flotation are treated by a variety of control methods. Usually all waste streams are combined, then treated by some combination of thickeners, clarifiers, and settling ponds. Some operators also use a flocculating agent (e.g., alum) to facilitate the settling of suspended material. Current practice is to recycle treated wastewater, either completely or partially. Water that is not recycled is discharged to the watershed or to active/abandoned working pits. The pH is adjusted before either recirculation or discharge.

Solid Waste Control--

When sufficient land is available, facilities dispose of their solid wastes on site. The residuals (waste fines, oversize, sludge) are dumped into previously mined areas, obsolete sedimentation ponds, or low-lying areas that need fill. Other operations must haul their solid waste to off-site landfills. Any valuable materials that are locally marketable, are recovered and sold.

Conclusions and Recommendations

Environmental problems associated with the industrial sand industry are similar to those encountered in the construction sand and gravel industry. The major concern lies in dewatering and ultimate disposal of waste fines, for which the same research and development recommendations apply as those presented for construction sand and gravel.

GYPSUM

Industry Description

Gypsum is a naturally occuring mineral found near large salt deposits. Formed as evaporites from marine waters, the deposits are found in stratigraphic beds with limestone and salt. "Gypsum" is a broad term that describes several different phases of the same material:

- Anhydrite (calcium sulfate) - $CaSO_4$
- Selenite (hydrated calcium sulfate) - $CaSO_4 \cdot 2H_2O$
- Calcined gypsum (hydrated calcium sulfate) - $CaSO_4 \cdot 1/2H_2O$

Anhydrite and selenite usually occur together; calcined gypsum is a manufactured product. Water is added to calcined gypsum to form plaster of paris, which quickly sets and hardens to become selenite again.

In 1974, crude gypsum was mined by 44 companies at 75 mines in 22 states (3). Thirteen of these mines were underground operations. California, Michigan, Iowa, Texas, and Oklahoma led in output with 60 percent of the total. Calcined gypsum was produced by 13 companies at 77 plants in 29 states, with California, Texas, New York, and Iowa accounting for 37 percent of the total. Production statistics for gypsum are presented in Section 1 of this report.

Gypsum, one of the most common building materials, is used universally for interior walls, partitions, and ceilings, either as plaster or in prefabricated products. Crude gypsum is marketed for use in cement, agriculture, or fillers. Calcined gypsum is marketed in the form of plaster or prefabricated products, such as lath, veneer base, sheathing, and wallboard. Also, beds of limestone or clay encountered in the overburden during mining of crude gypsum may be marketed for road materials.

Process Description

About 80 percent of the gypsum in the United States comes from open-pit mines and the rest from underground mines (59). In 1973, the stripping ratio for open-pit mines was 1.6 to 1, and average overburden for a 3-meter gypsum bed was only 4.8 meters. Open-pit mines use both draglines and tractors. Underground mines apply standard room-and-pillar methods, with trackless mining equipment. Figure 15 shows a flow diagram for mining and processing.

Gypsum is mined by using low-density, slow-speed explosives and drilling methods adapted to meet local conditions. The broken rock is loaded onto trucks or rail cars and transported to the processing facility.

Most gypsum mines use the "dry process" to beneficiate the ore. The alternative "wet process" is known as heavy-media separation. Both methods first crush the ore, usually at the mine site. Although most mines use gyratory crushers, some use jaw or impact crushers.

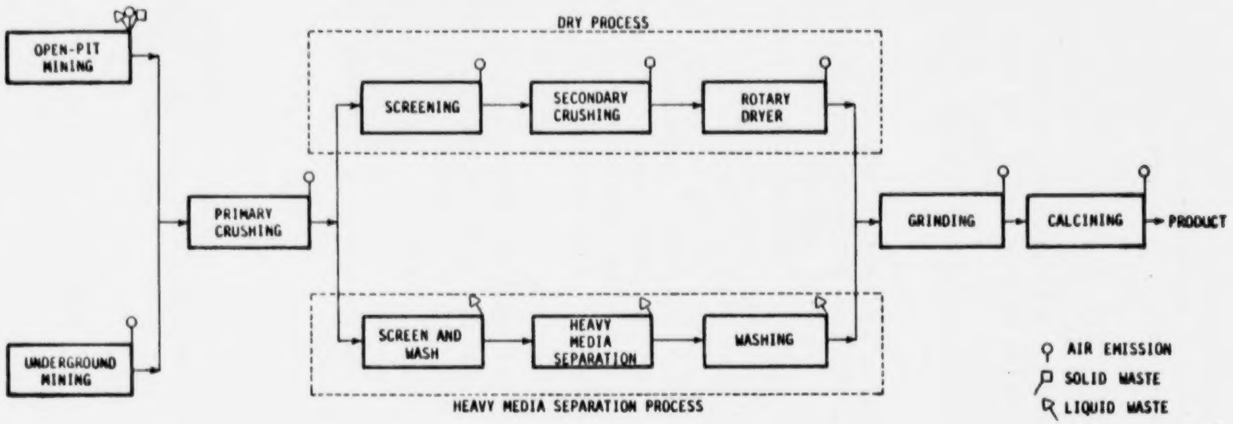
OPEN-PIT MINING
UNDERGROUND MINING
PRIMARY CRUSHING
DRY PROCESS
SCREENING
SECONDARY CRUSHING
ROTARY DRYER
SCREEN AND WASH
HEAVY MEDIA SEPARATION
WASHING
HEAVY MEDIA SEPARATION PROCESS
GRINDING
CALCINING
PRODUCT
AIR EMISSION
SOLID WASTE
LIQUID WASTE

Figure 15. Mining and beneficiating of gypsum.

Secondary crushing and screening operations usually take place in an enclosed building (crush house) away from the mining site. Rock from the primary crusher (which reduces the ore to -3.8 centimeters) is conveyed to the crush house and discharged onto a vibrating scalping screen. The screening operation recovers rock larger than 1.6 centimeters for the manufacture of Portland cement. Rock less than 1.6 centimeters is conveyed from screening to a secondary crusher for further size reduction. Removal of free moisture by drying sometimes is done in the primary or secondary crushing stages and almost always before the final size reduction step. Rotary dryers are used most often, with rock temperatures kept below 49°C to avoid dissociation of the combined water. Drying is necessary because wet material from the secondary crusher is not free-flowing and therefore difficult to handle.

When a total containment/recycle system (heavy-media separation) is used, the ore from the primary crushing step is screened and washed with recycled water, which removes undesirable particles from the main stream. The slurry then goes to a sink-float system, where magnetite and ferrous silica are used to separate impurities from the gypsum ore. The process consists of floating the mineral from the "heavy liquid" formed by the suspension of finely ground, heavy, ferromagnetic materials in water. The impurities are passed over screens to recover the magnetite and ferrous silica for recycling. The impurities are disposed of in nearby ponds and the product is transported to the facility for routine washing.

Final grinding, which reduces the rock size to 100 mesh, is accomplished almost exclusively by hammermills. After milling, some gypsum is washed or wet screened (when a white color is required), but most of the mineral is sent to vertical kilns or kettles to be calcined for 2 to 3 hours at 160°C to remove most of the hydration water. The calcined mineral is then processed into the desired final product.

Waste Streams

Table 14 presents a summary of multimedia wastes from the mining and beneficiation of gypsum. The following paragraphs explain in some detail, the air, liquid and solid waste streams.

Air Emissions--

Both open-pit and underground mining operations generate fugitive dust. Beneficiation sources of particulate emissions include primary and secondary crushing and screening. No emission estimates are available.

TABLE 14. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF GYPSUM

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Open pit mining	Fugitive particulates	N.A.[a]	Open pit mining (pumpout)	TSS	4 to 60 mg/ℓ	Open pit mining	Overburden waste	1100 kg/Mg gypsum mined[b]
Underground mining	Fugitive particulates	Negligible	Underground mining (pumpout)	pH	7.4 to 8.1[c]	Ore extraction	Gangue	N.A.[a]
Primary crushing	Particulates	N.A.[a]						
Screening	Particulates	N.A.[a]						
Secondary crushing	Particulates	N.A.[a]						
Rotary dryer	Particulates	20 g/kg gypsum[b]						
Grinding	Particulates	0.5 g/kg gypsum[b]						
Calcining	Particulates	45 g/kg gypsum[b]						

[a] See air, liquid, and solid waste sections.

[b] Ref. 59.

[c] Ref. 39. This range is for six facilities.

N.A.- Not available.

Probably the most significant air emissions in gypsum beneficiation emanate from the calcining operation, which generates 45 grams of particulate per kilogram of gypsum (68). The turbulant gases created by the release of the crystallization water carry calcined and partially calcined gypsum into the atmosphere. Particles are relatively large compared with those from processes in which the material is vaporized and condensed. However, gypsum dust is believed to be harmless.

Liquid Wastes--

If gypsum is dry processed, no process water is required in the mining, crushing, screening, or grinding operations. The only sources of liquid wastes are small amounts of mine drainage pumpout and runoff from storage piles.

In wet processing (heavy-media separation), water is needed for screening, washing and media recovery. Most of the wastewater is recycled along with runoff and no water is discharged into a watercourse (39). However, it is possible for some wastewater from the pond to leach out into the groundwater table.

Solid Wastes--

The only significant source of solid waste is the overburden removal from open-pit mining operations. About 1.1 megagrams of waste is generated for each megagram of gypsum mined (59).

Control Technology

The following paragraphs explain in some detail the various control options used in mining and beneficiation of gypsum.

Air Emissions Control--

Emissions from both underground and open-pit mines are minimized by using state-of-the-art control devices common to all mining activities. These are described in Section 3.

Most crushing and screening operations take place in a fully enclosed crush house, which is vented to a dry-dust collection device such as a fabric filter or a cyclone. The efficiency of these devices is not reported, but is estimated to be 90 to 95 percent based on knowledge of the process and equipment.

Liquid Waste Control--

Wastewater (pumpout and runoff) from both open-pit and underground mines is discharged into a pond. In the dry method, mine wastewater is discharged into a nearby watercourse after the solids have settled out. If heavy-media separation is used, most of the wastewater from the pond is recycled and used as process water.

Solid Waste Control--

Overburden waste and gangue are collected and allowed to pile up within the mine site. Although there are no general reclamation guidelines and standards, natural vegetation develops on these sites within a short time.

Conclusions and Recommendations

Gypsum is mined and beneficiated by environmentally acceptable methods in the United States, and no hazardous pollutants are generated.

Air pollutants are contained by conventional state-of-the-art techniques, and aqueous wastes are frequently recycled and used as process water. The only area that possibly warrants further research and development is the disposal/utilization of the large quantities (1.1 megagrams per megagram of ore) of overburden removed from open-pit mines, which now is allowed to accumulate at the mine site.

ASPHALTIC MINERALS

Industry Description

Asphaltic minerals are mixtures of hydrocarbons (natural or pyrogenous in origin) that are frequently accompanied by their nonmetalic derivitives. Since these natural asphalts include a wide variety of minerals, the term is sometimes expanded to include rocks in which the percentage of impregnation is comparatively low. Asphaltic minerals include bituminous sand, bituminous sandstone, bituminous limestone, tar sands, gilsonite, albertite, uintaite, elaterite, grahamite, impsonite, nigrite, wurtzilite, tabbyite, aeonite, and aegerite.

Substantial deposits of bituminous sand, sandstone, and limestone are found in many areas of the world. In the United States, deposits of commercial importance have been mined in Texas, Oklahoma, Louisiana, Utah, Arkansas, California, and Alabama. The bitumen content of these deposits, which are mined from open quarries, ranges from 4 to 14 percent (39). The material is used for paving in areas that are within economical shipping distance of the mine.

Another asphaltic mineral, which is 99.9 percent hydrocarbon but of lesser importance, is gilsonite. The only known deposits of this hard, brittle bitumen are in the Uintah basin of Utah and Colorado, where it is found in place, in veins, in locks, or in rock (60). Gilsonite production has been declining since 1974.

Grahamite is a mineral that resembles albertite in its jet-black luster. Deposits are found in veinlike masses in many areas, but rarely in large quantities (60). A large deposit in West Virginia was mined out several years ago; and deposits in Oklahoma, which were mined intensively in years past, are rarely mined now (39). Two deposits have been discovered in West Texas but are not considered significant enough to mine (61).

Wurtziline (also known as elaterite, aeonite, aegerite, and tabbyite)is a pyrobitumen that is closely related to gilsonite and uintaite and characterized by its hardness and infusibility. The main deposit of commercial importance is located in Uintah County, Utah. Wurtziline is used primarily in paints, varnishes, hard rubber compounds (as an extender), and weatherproofing and insulating compounds (39, 60).

Although U.S. production of native asphalt and related bitumen has fallen somewhat, it has remained between 1.6 and 1.8 x 10^6 megagrams per year for the past ten years (62). This production consists mainly of bituminous limestone, bituminous sandstone, bituminous sand, and gilsonite; therefore, the discussion in this report concentrates on the mining and beneficiation of these asphaltic minerals. Production statistics for the industry are presented in Section 1 of this report.

Process Description

All asphaltic minerals except gilsonite are mined by open-pit methods. The asphaltic mineral category is a broad one and involves various mining and beneficiation techniques. Figure 16 presents a composite flow diagram for the mining and beneficiation of asphaltic minerals.

As mentioned, the gilsonite deposits in Utah are mined underground. Because some fatal accidents occurred as a result of the explosive nature of the dust, it is now mined exclusively by hydraulic methods. High pressure water is applied, sometimes in conjunction with mechanical cutters, to fragment the ore. The ore is then recovered as a slurry and pumped to the surface where a portion is screened, dried, and packaged as a marketable sized material in its native state.

Material unsatisfactory for marketing is shipped by truck to Craig, Colorado, for further processing. Until recently it was pumped in a slurry through a 115 kilometer pipeline to Grand Junction, Colorado, for processing into coke and gasoline. The pipeline is now used in conjunction with oil shale mining.

Asphaltic sands (tar sands) are presently mined in Missouri and have been mined in Kentucky and Oklahoma. The terms "tar

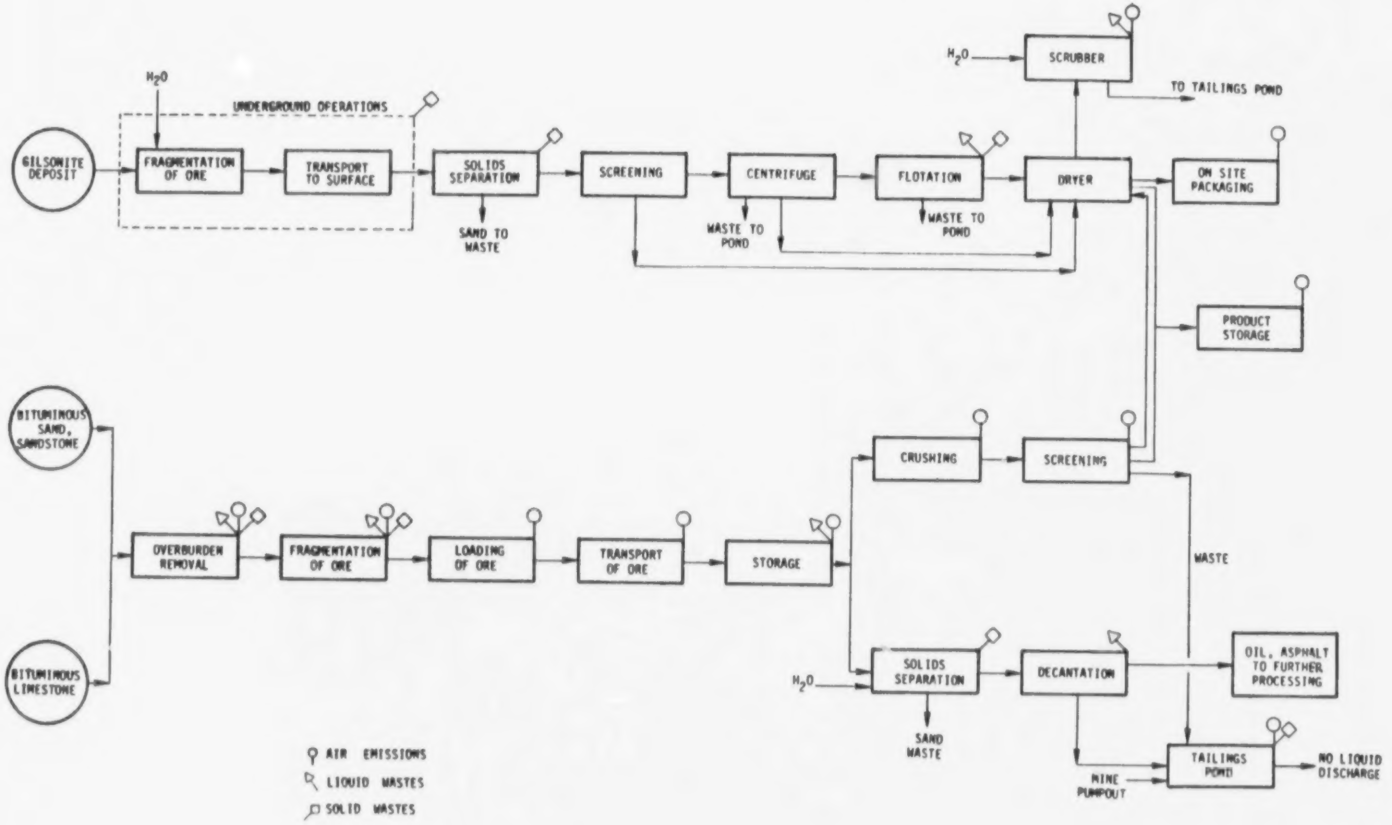
GILSONITE DEPOSIT
H_2O
UNDERGROUND OPERATIONS
FRAGMENTATION OF ORE
TRANSPORT TO SURFACE
SOLIDS SEPARATION
SAND TO WASTE
SCREENING
CENTRIFUGE
WASTE TO POND
FLOTATION
WASTE TO POND
DRYER
H_2O
SCRUBBER
TO TAILINGS POND
ON SITE PACKAGING
PRODUCT STORAGE
BITUMINOUS SAND, SANDSTONE
BITUMINOUS LIMESTONE
OVERBURDEN REMOVAL
FRAGMENTATION OF ORE
LOADING OF ORE
TRANSPORT OF ORE
STORAGE
CRUSHING
SCREENING
WASTE
H_2O
SOLIDS SEPARATION
SAND WASTE
DECANTATION
OIL, ASPHALT TO FURTHER PROCESSING
MINE PUMPOUT
TAILINGS POND
NO LIQUID DISCHARGE
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES

Figure 16 . Mining and beneficiating of asphaltic minerals.

sand" or "asphaltic sand" are used loosely to describe sands that contain both oil and asphalts. The rising cost of fuels will probably increase the pressure to develop these deposits for their value as fuel rather than paving, where virtually all of it now goes. Oil can be extracted by heating with hot water. Development of technology to economically recover fuels from asphaltic minerals could greatly increase mining activity.

The primary end use of asphaltic sandstone and asphaltic limestone is also in paving. Since crushed asphaltic limestone makes a much better paving material than the asphaltic sandstone, little asphaltic sandstone is mined where limestone deposits are available. However, some sandstone is blended with the limestone mixture for use in paving (63). Texas is the largest producer of total asphaltic minerals, and West Texas has the largest concentration of asphaltic limestone in the country. These limestone deposits contain about 9 to 13 percent bitumens. They lie close to the surface, so little overburden has to be removed. The deposits, which are between 3 and 25 meters thick, contain both rich and barren sections. Some Texas deposits have been reported to be from 50 to 65 meters thick (61). Mines are the conventional open-pit type, with crushing and screening on site.

Waste Streams

Table 15 summarizes multimedia wastes resulting from the mining and beneficiation of asphaltic minerals, and the following paragraphs explain in more detail the various air, liquid, and solid waste emissions.

Air Emissions--

Because of the explosive nature of gilsonite, dust control is an integral part of the mining and beneficiating process. The high-pressure water extraction method was developed after some fatal underground accidents, and all operations prior to drying are performed wet, thereby precluding air emissions.

Emissions from gilsonite drying are sent through a scrubber before discharge to the atmosphere. Some fugitive dust emissions result from packaging and storage, but they have not been quantified.

Because of their physical properties, air emissions from open-pit mining of bituminous sand, sandstone, and limestone are less than you would expect from a typical open-pit operation. Also, deposits are generally close to the surface, making fugitive dust emissions from overburden removal lower than average. This appears also to be true of the fragmentation and loading of the ore. However, no specific data were found on emission rates for any of these sources.

TABLE 15. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF ASPHALTIC MINERALS

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Underground operations	Fugitive particulate from mine ventilation	Negligible	Flotation Scrubber discharge	TSS BOD pH TDS Cd Chloride Sulfate	$17\ \mathrm{mg}/\ell^{b}$ $43\ \mathrm{mg}/\ell^{b}$ 8.2^{b} $2949\ \mathrm{mg}/\ell^{b}$ $<0.001\ \mathrm{mg}/\ell^{b}$ $0.15\ \mathrm{mg}/\ell^{b}$ $363\ \mathrm{mg}/\ell^{b}$	Underground operations	Gangue	
Dryer	Particulates	N.A.				Solids separation gilsonite	Sand	100-450 thousand $\mathrm{Mg/hr}^{d}$
Overburden removal	Fugitive particulates	N.A.	Overburden removal	Runoff	To tailings	Flotation	Tailings	
Fragmentation of ore	Fugitive particulates	N.A.	Fragmentation of ore	Runoff	To tailings	Overburden removal	Topsoil, subsoil & other strata	N.A.
Loading of ore	Fugitive particulates	N.A.	Ore storage	Runoff	To tailings			
Transport of ore	Fugitive particulates	N.A.	Decantation	Oil/tailings	To tailings	Fragmentation of ore	Gangue	N.A.
Ore storage	Fugitive particulates	N.A.	Tailings	N.A.	No discharge^{c}	Solids separation other than gilsonite	Sand, waste	N.A.
Crushing	Particulates	N.A.				Tailings	Tailings	N.A.
Screening	Particulates	N.A.						
Product storage	Fugitive particulates	N.A.						
On site packaging	Particulates	N.A.						
Tailings pond	Fugitive particulates	N.A.						

[a] For more complete information see air, liquid, solid waste sections.

[b] Ref. 39. For gilsonite mine.

[c] Ref. 39. No discharge under normal operations.

[d] Ref. 64. For gilsonite mine 1974.

N.A. - Not available.

Fugitive emissions from truck transport of the ore to the beneficiation site depend more on the location of the mine than on the ore. With the majority of the asphaltic minerals mined in arid or semiarid regions (Utah, West Texas), the fugitive emissions from this source can be expected to be higher than for the average mine. No specific emission data were found for either transport or storage of asphaltic minerals.

Because of the explosive nature of gilsonite, water sprays are used to control emissions from the crushing and screening processes. No information was found on the emissions from the crushing and screening of other asphaltic minerals. In fact no specific emission rates are available for any of the numerous asphaltic minerals.

With minor exceptions, most asphaltic minerals are used for highway paving. A few, notably gilsonite, are packaged on site for ultimate use in a wide variety of products such as paints, insulation, auto sealers, building board insulation, foundry processes, explosives, well cementing and printer's ink. No specific data were found on emissions from either the packaging or product storage of asphaltic minerals.

Because of the diversity of the tailings and the wide geographic distribution of the mines, it is impossible to estimate an emission factor for dried tailings.

Liquid Wastes--

All liquid wastes generated in gilsonite mining and beneficiation are recycled, largely because the mine is located in an arid region. Table 15 lists the concentrations of various pollutants sent to tailings.

All other asphaltic mining processes require considerably less process water than gilsonite beneficiation and under normal operating conditions no waste discharge occurs.

Some runoff from the overburden and gangue may occur, but no published data were found to support this. Nor were any found on mine pumpout from surface mines. Since the bulk of the asphaltic minerals is mined in arid or semiarid regions, mine pumpout and runoff are probably not serious problems.

Solid Wastes--

Solid waste emissions from the mining and beneficiation of asphaltic minerals consist of overburden, gangue, and tailings. The overburden produced in open-pit mining is usually stored in heaps adjacent to the pits. Deposits are normally close to the surface, and the quantity of overburden has been compared to that of a stone quarry.

A substantial quantity of gangue and tailing is generated in the mining and beneficiation of gilsonite. Table 15 shows the solid waste from this total operation. No information was found on the quantity of solid waste generated from any other asphaltic mineral mining processes.

Control Technology

Little data were found on pollution controls used in the asphaltic minerals industry. The following paragraphs explain the various control technologies known and their estimated efficiencies.

Air Emissions--

Overburden removal and ore fragmentation are among the most variable fugitive dust sources at surface mines. Dust emitted varies with composition, texture, and moisture content of the material; excavation procedures; equipment employed; etc. No information on specific controls or efficiencies was found.

Oiling or watering haul roads reduces dust generated from ore transport. An efficiency of 50 percent is assumed for control by watering.

Water sprays are used to suppress dust in gilsonite mining. This approach also helps to prevent explosion of the small dust particles.

Wet scrubbers are used to control dust emissions from the drying process, and the process water is sent to tailings for recycle. Control efficiency is unknown.

Air emissions from tailings can occur when the tailing pond becomes dry (i.e. when operations have ceased). These emissions can be reduced by either an intentionally or naturally formed crust. Emissions can be reduced up to 80 percent by this method (65).

Liquid Wastes--

Liquid wastes in the asphaltic mining industry are controlled by recycling process water and by tailings ponds. No discharge occurs from these ponds.

Solid Wastes--

Because the majority of the asphaltic minerals are mined in fairly remote areas, little pressure is applied toward reclaiming the disturbed land. Even the largest producing state does not require land reclamation. However, no information pointed to any problems caused by the solid waste generated at these mines. More data are definitely needed in this area.

Conclusions and Recommendations

Asphaltic minerals mining apparently causes no serious pollution problem. This is due in part to its small size and the location of the mines in remote dry areas.

It is believed that the new vague boundary between oil shale and asphaltic minerals may become even more vague as deposits become more valuable for their fuel value. If this happens and the industry expands both geographically and in size, research will be needed into the basic quantification of specific waste streams. At present, however, this research effort can be spent better on other minerals.

ASBESTOS AND WOLLASTONITE

Industry Description

Asbestos is a broad term applied to a number of fibrous mineral silicates that are incombustible and can be separated by suitable mechanical processing, into fibers of various lengths and thickness. Six varieties of asbestos are recognized: the finely fibrous form of serpentine known as chrysolite and five members of the amphibole group, i.e., amosite, anthophyllite, crocidolite, tremolite, and ackinolite. Chrysolite, which presently constitutes 93 percent of the world's asbestos production, has the empirical formula $3MgO \cdot 2SiO_2 \cdot 2H_2O$ (39). Wollastonite is a naturally occurring, fibrous calcium silicate, $CaSiO_3$ (39).

The United States is one of the leading consumers of asbestos yet in 1974 produced only 2 percent of the total world's production (4). (Production statistics for asbestos and wollastonite appear in Section 1 of this report.)

Seven U.S. companies engaged in the production of asbestos in 1974. Four of the operations were in California and one each in Arizona, North Carolina, and Vermont (4). U.S. wollastonite is mined by one company in New York (39).

The construction industry presently uses most of the asbestos fibers in such products as asbestos cement pipe and sheeting, roofing products, flooring products, paints, and caulking. These fibers are also used in textiles, clothing, theatre curtains, woven brake linings, clutch facings, electrical insulation materials, and high-pressure marine insulation (4). Wollastonite is useful as a ceramic raw material, as a filler for plastics and asphalt products, as a filler and an extender for paints, and as an ingredient in welding rod coatings. Because of its fibrous, noncombustible nature, wollastonite is also being considered as a possible substitute when asbestos is objectionable in certain products (39).

Process Description

Most asbestos mines in the United States are open-pit; a single mine in Arizona uses underground methods (4).

The ore is conveyed from mine to mill by truck. Although milling methods vary in detail, they are all identical in principle. Four of the five U.S. facilities that mine and process asbestos use a dry method, the fifth a wet method (39). Figure 17 shows the two methods.

In the dry process, the quarried asbestos ore is crushed in jaw or gyratory crushers to a size of 3.8 to 5.1 centimeters. The crushed ore is dried to 1 percent or less moisture in rotary or vertical dryers before being crushed again in hammermills, cone crushers, or gyratory crushers. The ore is sent from the secondary crushers to a series of shaker screens, where the asbestos fibers are separated from the rock and air-classified into a series of grades according to length. The graded fibers are bagged for shipment (39).

In the wet process, ore is "ploughed" in horizontal benches and allowed to air-dry. It is then screened and transported to the mill for processing. Processing consists of further screening, wet crushing, fiber classification, filtering, and drying. Process water is used for wet processing and classifying of asbestos fibers.

The only U.S. producer of wollastonite uses the underground room and pillar method to extract the ore, then trucks it to the processing facility. Processing is dry and consists of three stage crushing with drying following the primary crushing. The ore is screened, then various sizes are fed to high-intensity magnetic separators to remove garnet and other ferromagnetic impurities. The purified wollastonite is ground in pebble or attrition mills to the desired product sizes. Figure 18 shows a process flow diagram for wollastonite mining and beneficiating.

Waste Streams

Table 16 presents a summary of multimedia wastes from the mining and beneficiation of asbestos and wollastonite. The following paragraphs explain in more detail the various air, liquid, and solid wastes associated with this industry.

Air Emissions--

Asbestos fibers and other particles are emitted during removal of overburden and preparation of the ore body for open-pit mining. Further release occurs during drilling and ore-breaking. Particles are also released in underground mining

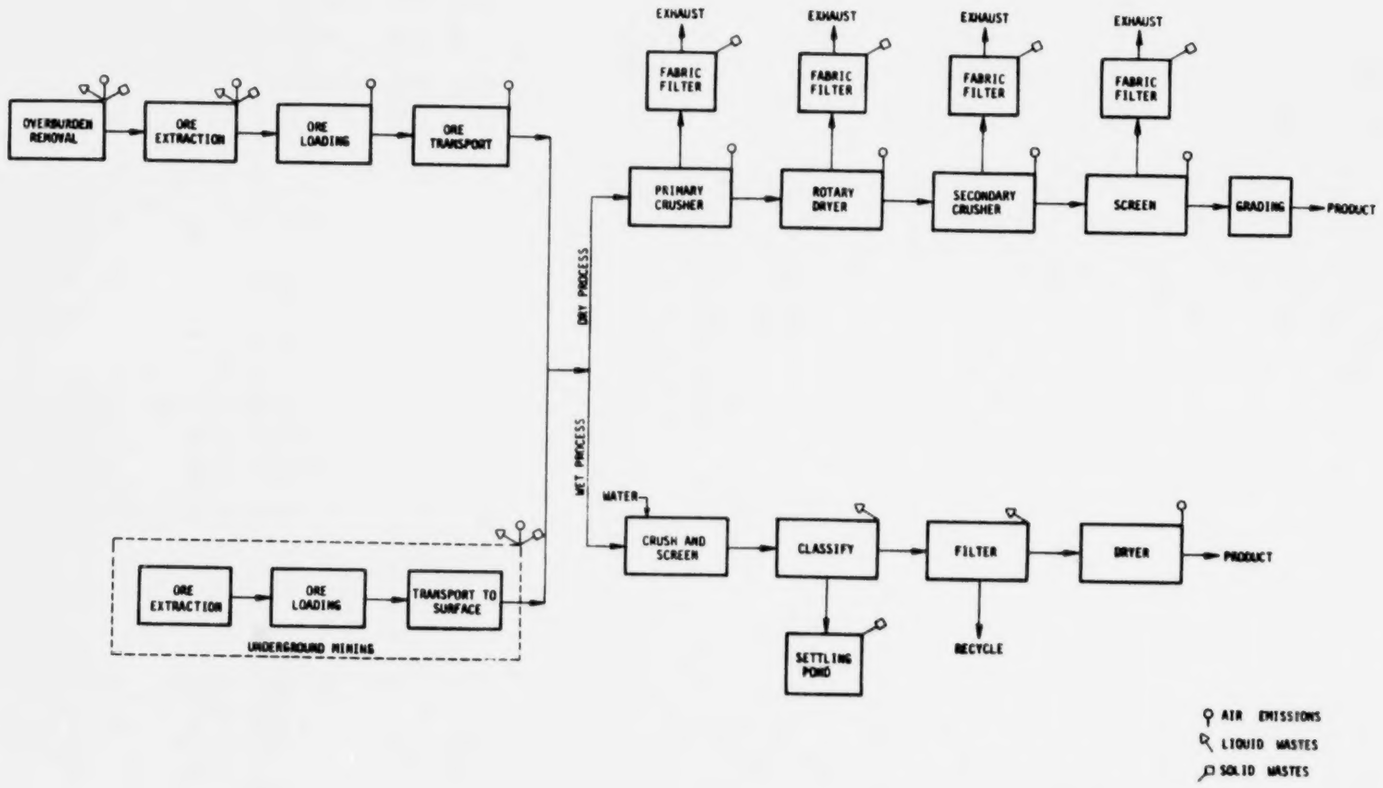
OVERBURDEN REMOVAL
ORE EXTRACTION
ORE LOADING
ORE TRANSPORT
DRY PROCESS
WET PROCESS
EXHAUST
FABRIC FILTER
EXHAUST
FABRIC FILTER
EXHAUST
FABRIC FILTER
EXHAUST
FABRIC FILTER
PRIMARY CRUSHER
ROTARY DRYER
SECONDARY CRUSHER
SCREEN
GRADING
PRODUCT
ORE EXTRACTION
ORE LOADING
TRANSPORT TO SURFACE
UNDERGROUND MINING
WATER
CRUSH AND SCREEN
CLASSIFY
FILTER
DRYER
PRODUCT
SETTLING POND
RECYCLE
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES

Figure 17. Mining and beneficiating of asbestos.

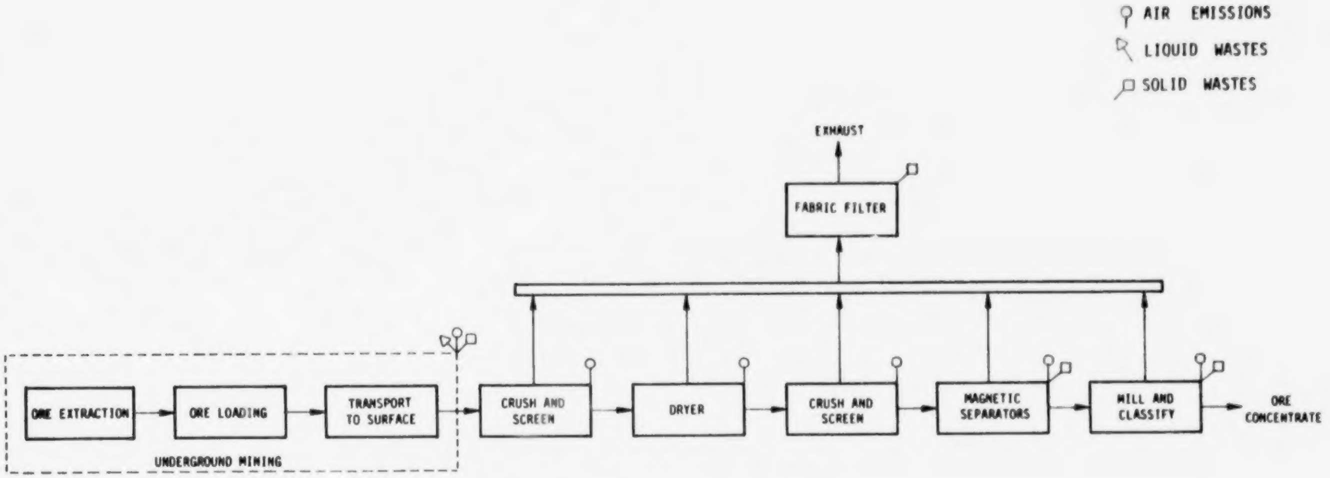
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES
EXHAUST
FABRIC FILTER
ORE EXTRACTION
ORE LOADING
TRANSPORT TO SURFACE
UNDERGROUND MINING
CRUSH AND SCREEN
DRYER
CRUSH AND SCREEN
MAGNETIC SEPARATORS
MILL AND CLASSIFY
ORE CONCENTRATE

Figure 18. Mining and beneficiating of wollastonite.

TABLE 16. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF ASBESTOS AND WOLLASTONITE

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal			Overburden removal	TSS[a] Fe Asbestos pH	2.0 mg/ℓ 0.15 mg/ℓ 1.0 to 1.8 x 10^6 fibers/liter 8.4 to 8.7	Overburden removal	Gangue[b]	Up to 96% of ore
Ore extraction	Fugitive particulates	N.A.	Ore extraction Underground mining	N.A.	N.A.	Ore extraction Underground mining	Gangue	N.A.
Ore loading								
Ore transport			Classify	TSS[a] Magnesium Sodium Chloride Nickel pH	160 mg/ℓ 48 mg/ℓ 345 mg/ℓ 104 mg/ℓ 0.1 mg/ℓ 7.8	Fabric filter	Collected particulates	N.A.
Underground mining	Particulates	N.A.				Settling pond	Sludge	N.A.
Primary crusher	Particulates	N.A.	Filter	N.A.	N.A.			
Rotary dryer	Particulates	N.A.						
Secondary crusher	Particulates	N.A.						
Screen	Particulates	N.A.						

[a] Ref. 39.

[b] Telephone conversation between Vijay Patel of PEDCo and Chris Jones, Vermont Air Pollution Control Agency, Montpelier, Vermont, April 1977.

N.A. - Not available.

operations. The quantity of emissions has not been reported from any of these sources.

Each piece of process equipment in the dry milling of asbestos produces dust emissions.

Dust sources are minimized in the wet process by use of water throughout the operation.

Virtually every process step in the mining and beneficiation of wollastonite is a potential generator of particulate emissions. Quantitative data on these emissions are not available, however, because of the proprietary nature of the process.

Liquid Wastes--

Since no process water is used for dry processing asbestos, sources of liquid wastes are few. The major source is mine pumpout. At one facility the flow ranges from 380 to 2270 liters per minute depending on rainfall (39). The following tabulates the analytical data for this discharge:

TSS	2.0 mg/ℓ
Fe	0.15 mg/ℓ
Asbestos	1.0 to 1.8 x 10^6 fibers/liter
pH	8.4 to 8.7

In the wet process, large quantities of water are used. Water consumption at one facility is reported to be 4300 liters per megagram of asbestos milled (39). The wastewater discharge from the same facility amounts to 860 liters per megagram of asbestos milled. The rest of the water is either lost with the product, recirculated, or lost in tailings.

The discharge parameters from this facility are:

TSS	1160 mg/ℓ
Magnesium	48 mg/ℓ
Sodium	345 mg/ℓ
Chloride	104 mg/ℓ
Nickel	0.1 mg/ℓ
pH	7.8

The filtrate from the filtration process is recycled to the crushing and screening process (39).

Mining and beneficiation of wollastonite does not involve any water use. Noncontact cooling water amounts to 235 liters per megagram of product (39).

Solid Wastes--

Open-pit mining produces large quantities of overburden and waste rock. One of the largest asbestos mines in the country reports up to 96 percent of mined ore is discarded as waste.* Underground mining produces only a small amount of waste rock.

In the dry process, one of the largest sources of solid wastes is the dust collected by the fabric filters.

In the wet process, solid wastes accumulate in the form of sludge in the settling ponds.

In the mining and beneficiation of wollastonite, approximately 40 percent of the ore mined is discarded as solid waste.** Roughly 10 percent of this waste comes from mining and the rest from beneficiation of the ore. The magnetic separation process is the largest source of solid waste in the beneficiation operation.

Control Technology

Control technologies as applied to the asbestos and wollastonite mining industry are explained in the following paragraphs.

Air Emissions Control--

Various types of wetting agents reduce dust emissions at most open-pit mines. One mine uses a fabric filter to control primary dust from the drilling operation.* At another mine in California, the relatively high moisture content (15 percent) of the ore keeps dust emissions at a minimum.***

Most mines use fabric filters to control dry milling operations. All conveyors are enclosed, and conveyor transfer points are aspirated to the fabric filters.

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*Telephone conversations between Vijay Patel of PEDCo and Chris Jones, Vermont Air Pollution Control Agency, Montpelier, Vermont. April 1977.

**Telephone conversation between Vijay Patel of PEDCo and Loren Choate, Interforce Corporation, Willoboro, New York. May 1977.

***Telephone conversation between Vijay Patel of PEDCo and Bob Bashran, Fresno County Air Pollution Conference Office, Fresno, California. April 1977.

The one existing U.S. wollastonite facility uses seven fabric filters at various locations within the process to minimize dust emissions.*

Liquid Waste Control--

One dry process facility is reported to treat quarry pumpout discharge with sulfuric acid to lower the pH of the highly alkaline ground water that collects in the quarry (39).

The wet processing facility treats process water discharge in settling ponds. Suspended asbestos fibers settle out in the primary settling pond before the clarified effluent is decanted to the secondary settling pond. The facility does not discharge to surface waters (39).

The one U.S. wollastonite mine discharges untreated noncontact cooling water to a nearby river (39).

Solid Waste Controls--

Waste rock from open-pit mining is disposed of in a tailing pond. Some facilities also send dust collected from the fabric filters to the tailing pond, whereas other facilities plough the dust back into the process.

Sludge accumulated in the settling ponds is periodically dredged. The wastes are piled along side the pond, allowed to dry, and then landfilled. Usually no mitigating measures are undertaken to retard windblown materials.

Solid wastes from the mining and beneficiation of wollastonite are sent to a tailings pile. From there it is hauled off site to be used as fill material or as an agricultural fertilizer.*

Dust collected in the fabric filters in the wollastonite mine is either ploughed back into the process or sent to the tailings pile.*

Conclusions and Recommendations

Asbestos has recently been recognized as a potential carcinogen. Asbestos fibers may be liberated into the air in dangerous amounts at all stages in the mining and milling of the ore. Because of the carcinogenic properties of asbestos, most research should be directly related to reducing adverse health effects.

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*Telephone conversations between Vijay Patel of PEDCo and Loren Choate, Interface Corporation, Willoboro, New York. May 1977.

Methods of sampling, identifying and quantitating airborne asbestos need to be developed further in coordination with continuing studies involving animals and man to ensure biological relevance of environmental data.

Quantitative methods for measuring airborne asbestos should be applied widely to determine the natural background and the concentration and distribution of fibers in the air near various sources.

The potential use of tailings from asbestos mines in the manufacture of building products should be further investigated.

LIGHTWEIGHT AGGREGATES

Industry Description

Lightweight aggregates include several minerals or rock materials used as fillers in concrete, plaster, insulation, and for other structural materials, and as an insulator (25). Some lightweight aggregates occur naturally (pumice) whereas others are manufactured from natural minerals (perlite and vermiculite).

Minerals used for lightweight aggregate production are extracted by open-pit methods. Preliminary beneficiation (e.g. crushing, screening, milling) of perlite and vermiculite is usually performed at the mine site, but final processing (expansion) is normally accomplished at facilities located closer to the consumer. Pumice, on the other hand, is processed completely at facilities located adjacent to the mining operations.

Perlite--

The name perlite is commonly used to describe both unprocessed (crude perlite) and processed (expanded perlite) material. Crude perlite is a natural, glassy, rhyolitic rock that is essentially a metastable amorphous aluminum silicate (5). Its abundance of spherical or convoluted cracks causes it to break into small pearl-like masses, usually less than a centimeter in diameter, as a result of the rapid cooling of acidic lavas. The chemical constituents of perlite include silicon oxide (71 to 75 percent), aluminum oxide (12.5 to 18 percent), potassium oxide (4 to 5 percent), and sodium and calcium oxides (1 to 4 percent) (5). Perlite may also contain traces of various metal oxides. Crude perlite has the unusual characteristic of expanding to about 20 times its original volume when heated, and expanded perlite has numerous constructional and industrial applications because of its low density, low thermal conductivity, and high sound adsorption.

The United States leads the world in production and consumption of perlite. The industry has enjoyed continuous growth in its brief 30-year history, and upward trend of perlite production is expected to continue over at least the next 10 years. (See Section 1 of this report for present and future production statistics.)

The total domestic production of crude perlite in 1974 came from twelve surface-mine operations in six Western States (5). New Mexico, the major producing state, supplied 88 percent of the total crude perlite mined. Other states with active perlite mines include Colorado, Texas, Arizona, Nevada, and California. Expanded perlite was produced at 76 facilities in 30 states in 1974. The principal producing states are Illinois, Mississippi, Kentucky, Pennsylvania, and Colorado.

The commercial uses of perlite are numerous and depend upon the properties of the expanded material. Approximately 70 percent of the expanded perlite is consumed as an aggregate for plaster and concrete and prefabricated insulating board (39). Some perlite is used as an insulator, and as such provides a high degree of fireproofing. Perlite is also used as a filter-aid material in the treatment of industrial wastes water, and in the beverage, food, and pharmaceutical processing industries.

No by-products/coproducts are associated with the perlite industry.

Pumice--

Pumiceous materials (minerals of volcanic origin) include pumice, pumicite, scroia, and cinder (7). These volcanic rocks have a variety of applications dependent upon the unique characteristics of the materials, such as abrasiveness, inertness, and light weight. Commercial usages have resulted in the application of the term pumice to all rocks of volcanic ash origin.

Pumice is essentially an aluminum silicate of igneous origin with a cellular structure formed by a process of explosive volcanism (7). Pumicite is a pumice that has been subjected to additional volcanism, which breaks down the cellular structure to form a finely divided, unconsolidated material. Volcanic cinder and scoria are uncemented volcanic fragments formed from a basic igneous magma.

The United States is one of the world's largest producers and consumers of pumiceous materials. Over the past 11 years this country has produced an average of 21.5 percent of the world production (7). Projections indicate the United States will maintain its current position in production and consumption. (See Section 1 of this report for production statistics.)

In 1974 pumiceous materials were produced by 290 operations in 12 states (7). The major producing states were Arizona, California, Hawaii, Nevada, and New Mexico.

Both unprocessed (crude) and processed pumiceous materials are sold on the commercial market. Principal end uses include abrasives for cleaning and scouring compounds, concrete aggregate and admixtures, railroad ballast, road construction, and landscaping. Additional uses of pumiceous materials include diluents, absorbents, catalyst carriers, decolorizing and purifying agents, and filler and extenders for paints, enamels, varnishes, plastics, and rubber goods.

Vermiculite--

Vermiculite is a mica-like mineral and, like perlite, has the unique property of exfoliating to a low-density material when heated. The term vermiculite is applied to both the crude ore and the expanded product.

In 1974 the United States accounted for 62 percent of the vermiculite output and 58 percent of the demand in the world market (8). (See Section 1 of this report for production statistics.) The United States is now self-sufficient in vermiculite production and ore reserves are thought to be sufficient to meet future needs.

In 1975 crude vermiculite was extracted from only two locations in the United States, a large mine near Libby, Montana (the largest vermiculite mine in the world), and several small mines near Enoree, South Carolina. Efforts are being made to develop a vermiculite deposit near Louisa, Virginia, but zoning problems are delaying this action. Crude vermiculite was processed (exfoliated) at 53 plants in 31 states in 1974 (8). The major producing states, accounting for 46 percent of the total production, were California, Florida, New Jersey, South Carolina, and Texas. Most vermiculate exfoliating facilities produce less than 5000 megagrams annually.

Vermiculite has a broad range of uses since the expanded product is noncombustible, lightweight, insoluble, freeflowing, chemically inert, resilient, and nonabrasive. These characteristics make it particularly useful in the construction and agricultural industries. It has been used specifically in thermal insulators, in additives for lightweight concretes and plasters, and in fire barriers, and more recently, because of its excellent adsorption characteristics, in chemical processing, water and air purification, and other areas.

Process Description

Deposits of lightweight aggregates considered in this study (perlite, pumice, and vermiculite) are all similar in that they 1) result from volcanism, 2) lie close to the surface, and 3) are covered with a relatively thin layer of unconsolidated material. In the past a small amount of lightweight aggregate was recovered from underground operations, but all current mining is open-pit. Since the overburden and most deposits consist of unconsolidated material, equipment such as bulldozers, pan scrapers, draglines, and power shovels are used to remove overburden and loosen, extract, and load the mineral. Periodically, some consolidated material is encountered that requires loosening by rippers or blasting. Extracted ore is loaded onto trucks, carryalls, or conveyor chutes and transported to the processing mill, which is usually located adjacent to the mine site. The processing of perlite, pumice, and vermiculite is illustrated on Figure 19 and described in the following paragraphs.

Perlite--

Perlite ore is reduced by a jaw crusher and, occasionally, a secondary roll crusher. When necessary, the crude is passed through a rotary dryer (usually oil-fired) to reduce the moisture content from 2 to 5 percent to less than 1 percent. The dried perlite is screened and further reduced by a ball or rod mill to the specified size for expansion. Care must be taken during the crushing steps to keep to a minimium particles that are too small for expansion. These excessively fine particles (-100 mesh), which are generally considered waste, are separated from useful sizes (-4 to +100 mesh) by screening and/or air classification. Following classification, the perlite usually is stored in uncovered stockpiles until being trucked to off-site expansion furnaces located closer to the consumer. This classification practice minimizes transportation expenses. Waste fines generated throughout the processing circuit (up to 25 percent of the mill feed) are either collected and bagged (if salable) or dumped on site.

Pumice--

Processing of pumice first involves the use of scalping screens to remove organic debris and oversized material. Primary (and sometimes secondary) crushers are then applied to reduce the oversize material. Occasionally the crude ore requires drying, which is done in a rotary dryer either before or after the crushing step. If the pumice is to be used in road surfacing, it is removed at this point. If it is to be used as an abrasive, however, it must be ground with a rod or ball mill before sizing by either air classification or bolting machines. The end product usually is bagged by size and stored until shipment.

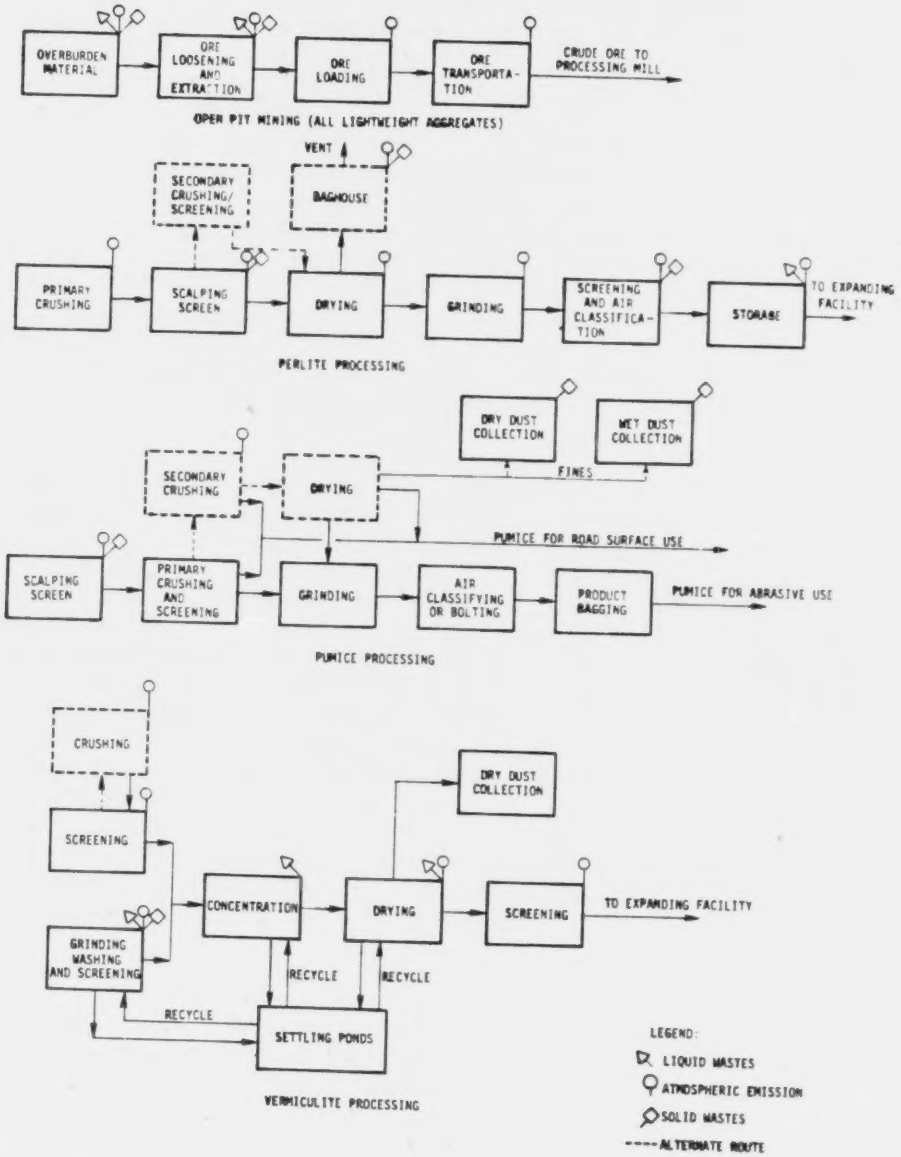
OVERBURDEN MATERIAL
ORE LOOSENING AND EXTRACTION
ORE LOADING
ORE TRANSPORTATION
CRUDE ORE TO PROCESSING MILL
OPEN PIT MINING (ALL LIGHTWEIGHT AGGREGATES)
VENT
SECONDARY CRUSHING/ SCREENING
BAGHOUSE
PRIMARY CRUSHING
SCALPING SCREEN
DRYING
GRINDING
SCREENING AND AIR CLASSIFICATION
STORAGE
TO EXPANDING FACILITY
PERLITE PROCESSING
DRY DUST COLLECTION
WET DUST COLLECTION
FINES
SECONDARY CRUSHING
DRYING
PUMICE FOR ROAD SURFACE USE
SCALPING SCREEN
PRIMARY CRUSHING AND SCREENING
GRINDING
AIR CLASSIFYING OR BOLTING
PRODUCT BAGGING
PUMICE FOR ABRASIVE USE
PUMICE PROCESSING
CRUSHING
SCREENING
DRY DUST COLLECTION
CONCENTRATION
DRYING
SCREENING
TO EXPANDING FACILITY
GRINDING WASHING AND SCREENING
RECYCLE
RECYCLE
RECYCLE
SETTLING PONDS
VERMICULITE PROCESSING
LEGEND:
LIQUID WASTES
ATMOSPHERIC EMISSION
SOLID WASTES
----ALTERNATE ROUTE

Figure 19. Mining and beneficiating of lightweight aggregates (perlite, pumice, and vermiculite).

Vermiculite--

Vermiculite ore is currently processed in only two locations in the United States: Libby, Montana, and Enoree, South Carolina. Although these facilities differ operationally, they share some similarities. Processing at the Montana plant combines dry and wet processes using crushers, screens, jigs, and spirals. Since most of the extracted ore is in a disseminated form, crushing usually is not required and the ore is passed directly through the screening operation to the concentrators (25). However, crushing is required occasionally to reduce oversized material. The screened (and sometimes crushed) ore is concentrated by jigs and spirals. The concentrate is then dewatered (generally by centrifuges or rotary dryers), sized, and stored for shipment to the expansion facilities. The South Carolina operations differ from those described above in that almost all the ore requires some size reduction and it is washed to remove clay slimes before being concentrated. Following grinding, washing, and screening the ore is concentrated in flotation units. As in Montana, the concentrate is then dewatered, sized, and stored for shipment to expansion plants.

Waste Streams

The extraction and processing of lightweight aggregate minerals result in the generation of various atmospheric, liquid, and solid wastes. These waste streams are shown in Table 17 and discussed in detail in the following paragraphs.

Air Emissions--

Sources of atmospheric emissions associated with the mining of lightweight aggregates are similar to those related to other mineral mining industries. Fugitive particulates may result from any one of a number of operations such as overburden removal and ore loosening, extraction, loading, and transportation. The moisture content of crude perlite, vermiculite, and pumice ores is usually high enough to make fugitive emissions minimal; however, when the ore and associated waste materials dry, they can generate large quantities of particulate dust. This is especially true at perlite and pumice mines, which usually are located in areas with semiarid to arid climate. Most of the fugitive particulates generated at lightweight aggregate mining sites result from truck transport of crude ore over unpaved roads. No data are available concerning the emissions of fugitive particulates from these various sources in the lightweight aggregate industry.

Particulates are the major atmospheric pollutant associated with the processing of lightweight aggregates. The drying operation is the largest source at all perlite, pumice, and vermiculite mills. Perlite and vermiculite dryers have been found to

TABLE 17. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF LIGHTWEIGHT AGGREGATES (PERLITE, PUMICE, VERMICULITE)

	Air			Liquid			Solid		
	Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Lightweight Aggregate Mining	Overburden removal	Fugitive particulates	N.A.	Pit pumpout	TSS	N.A.	Overburden removal and ore extraction	Topsoil, subsoil, and associated waste rock	3.88 kg/Mg of feed^c
	Ore extraction	Fugitive particulates	N.A.	Surface runoff	TSS	N.A.			
	Ore loading	Fugitive particulates	N.A.						
	Ore transportation	Fugitive particulates	N.A.						
Perlite Processing	Primary crushing	Particulates	0.25 kg/Mg of feed^a	Wet scrubber	TSS	N.A.	Dry particulate collection devices	Collected particulates	250 kg/Mg of feed^d
	Scalping screen	Particulates	0.56 kg/Mg of feed^b						
	Secondary crushing	Particulates	0.75 kg/Mg of feed^a						
	Drying	Particulates	55.97 kg/Mg of feed						
	Screening	Particulates	0.60 kg/Mg of feed^b						
	Grinding	Particulates	3.0 kg/Mg of feed^a						
	Primary sizing screens	Particulates	1.21 kg/Mg of feed^b						
	Secondary sizing screens	Particulates	1.41 kg/Mg of feed^b						
	Air classification	Particulates	0.92 kg/Mg of product^b						
	All conveyors and elevator transfer	Particulates	1.23 kg/Mg of product^b						
	Scalping screen	Particulates	N.A.	Wet scrubber	TSS	N.A.	Dry particulate collection devices	Collected particulates	250 kg/Mg of feed^d
	Primary crushing	Particulates	0.25 kg/Mg of feed^a						

(continued)

TABLE 17. (continued)

	Air			Liquid			Solid		
	Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Pumice	Screening		N.A.						
Processing	Sedondary crushing	Particulates	0.75 kg/Mg of feed[a]						
	Drying		N.A.						
	Grinding	Particulates	3.0 kg/Mg of feed[a]						
	Air classification	Particulates	N.A.						
	Bagging facility	Particulates	N.A.						
	All conveyors and elevators	Particulates	N.A.						
	Grinding	Particulates	0.25 kg/Mg of feed[a]	Process wastewater	TSS	N.A.			
Vermiculite	Screening	Particulates	0.33 kg/Mg of feed[c]						
Processing	Drying	Particulates	8.6 kg/Mg of feed[c]						
	Loading facility	Particulates	0.20 kg/Mg of feed[c]						

[a] Ref. 49. Based on emission factors for stone quarrying.

[b] Telephone conversation between Jack Greber of PEDCo and David Duran, State of New Mexico Environmental Improvement Agency, Sante Fe, New Mexico. April 1977. Value based on observation of a single perlite mining and processing facility.

[c] Telephone conversation between Jack Greber of PEDCo and John Bolstad, Montana State Department of Health and Environmental Sciences, Helena, Montana. April 1977. Based on values from a single vermiculite mine.

[d] Ref. 7. Calculated as 25 percent of the mill feed. Represents total particulates collected from various stages throughout the processing operations.

N.A. - Not available.

emit total particulates at a rate of 55.97 kilograms* and 8.6 kilograms** per megagram of feed, respectively. Data are not available on emissions from pumice dryers, but they are expected to be similar to those reported for perlite dryers. Additional sources of particulates at lightweight aggregate plants include crushing, screening, grinding, conveying, classifying, and loading operations. Emissions from these operations are most apparent at feed and discharge points. As Table 17 indicates, initial processes (primary crushing and screening) generate less emissions than secondary and final processing operations (e.g. drying, grinding, classifying) because the crude ore handled during and after drying operations is of smaller particle size and drier than the ore handled in initial operations. Other factors that influence the amount of emissions released from the various sources include the type of rock processed and the type of processing equipment.

Fugitive particulates are also a problem at perlite, pumice, and vermiculite processing facilities. The major source is vehicular traffic. Fugitive dust is a greater problem at perlite and pumice operations because they are located in areas with semiarid to arid climate. No data are available on fugitive particulates for the lightweight aggregates industry.

Atmospheric wastes associated with the mining and beneficiating of perlite and pumice do not contain any potentially hazardous materials; however, the ore recovered from the large vermiculite mine near Libby, Montana is known to contain asbestos fibers.** The amount of asbestos released to the atmosphere has not been monitored at this facility, but microscopic analysis of the ore revealed an asbestos concentration of less than 5 fibers per cubic centimeter of ore.

Liquid Wastes--

Most perlite and pumice operations employ dry processing methods and therefore produce no wastewater (39). Several plants use minor amounts of water to control fugitive dust, but the water is evaporated or absorbed quite rapidly and results in no discharge. Some facilities have small amounts of discharge resulting from the use of wet scrubbers. Pit pumpout and surface runoff are not a problem at perlite and pumice operations because of their location in areas with relatively dry climate.

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*Telephone conversation between Jack Greber of PEDCo and David Duran, State of New Mexico Environmental Improvement Agency, Santa Fe, New Mexico. April 1977.

**Telephone conversation between Jack Greber of PEDCo and John Bolstad, Montana State Department of Health and Environmental Sciences, Helena, Montana. April 1977.

Vermiculite mills do generate process wastewater; however, the water is pumped to settling ponds and recycled, so no discharge occurs. Pit pumpout and surface runoff are also collected in settling ponds. No information is available on the amount of wastewater generated at vermiculite operations.

Solid Wastes--

The lightweight aggregate mining industry is faced with the usual problems of judicious disposal of overburden and associated waste rock and consideration of the ultimate condition of abandoned mine sites. One vermiculite mine generated as much as 3.88 megagrams of overburden and gangue for each megagram of ore extracted.* Amounts are not available for either perlite or pumice mining.

Waste fines collected from processing operations such as screening and drying present a solid waste disposal problem at most perlite and pumice milling facilities. The volume of fines generated can amount to as much as 25 percent of the mill feed.

Control Technology

Various waste control options used in mining and beneficiating of lightweight aggregates are explained in the following paragraphs.

Air Emissions Control--

Fugitive particulate emissions are not a major problem at vermiculite mining operations because extracted ore has a fairly high moisture content. The few minor problems are minimized by wetting, sweeping, and general good housekeeping practices.

Fugitive dust is a major problem at perlite and pumice mining and beneficiating operations because these facilities are located in areas with dry climates. Little attempt is made to control the fugitive particulates in these areas since water scarcity prevents the use of wetting, the most common control practice.

Vermiculite processing operations generate some source particulate emissions; however, most mills have reduced these emissions by converting from dry to wet beneficiation techniques. The major sources of particulates include drying and the operations subsequent to drying, such as sizing, loading, and transfering. Source particulates are controlled by baghouses, cyclones, and venturi scrubbers. These control devices achieve efficiencies ranging between 95.0 and 99.7 percent.

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*Telephone conversation between Jack Greber of PEDCo and John Bolstad, Montana State Department of Health and Environmental Sciences, Helena, Montana. April 1977.

Pumice and perlite processing generates source particulates throughout the entire beneficiating operation. The major sources are crushing, screening, grinding, and drying. Crushing, grinding, and screening operations take place in enclosed buildings, with emissions vented to baghouses. Particulates from drying operations are usually controlled by a combination of a baghouse and a cyclone. Efficiencies of the cyclones and baghouses have been measured at 95 and 99.5 percent, respectively.

Liquid Waste Control--

Beneficiation of perlite or pumice produces no wastewater because water is not used in the process. Several pumice processing facilities use scrubbers for particulate control, however, and therefore have a minor amount of liquid waste to treat. The waste streams at these facilities are pumped to settling ponds, where the solids are impounded (39). The treated water is recycled to the scrubbers. The amount of scrubber wastewater treated is not known.

Vermiculite processing operations do generate some liquid wastes as a result of wet beneficiation techniques. The process wastewater is pumped to a series of settling ponds, where the solids are impounded (39). Some facilities use flocculants such as aluminum sulfate to facilitate settling. Because all clarified water is recycled, no discharge results. As settling ponds become filled, new ones are constructed. Some water may escape from the ponds by seepage or percolation. No values are available on the amount of wastewater going to settling ponds or the amount escaping from them.

Solid Waste Control--

The major sources of solid waste at lightweight aggregate mines are overburden and gangue. These wastes are disposed of by returning them to the mine during reclamation. Mine reclamation procedures depend on state regulations but usually involve grading the land back to its original contour and revegetating it.

The fine particulates collected from the various processing operations at lightweight aggregate mills present an additional solid waste disposal problem. The fines are returned to the process, sold as a by-product, or disposed of on site.

Conclusions and Recommendations

Lightweight aggregate mining has the usual problem of judicious disposal of overburden and consideration of the ultimate condition of the abandoned mine site. Most abandoned mines are located on governmental property and the sites are returned to the conditions that prevailed prior to mining activities. Some mines, however, are located on private property, and many of these sites are not reclaimed.

The major problem associated with lightweight aggregate mining and milling results from the generation of large amounts of fines. These fines produce related dust problems, and the fines collected by dry dust collection devices present a solid waste disposal problem. Although some fine particulates are returned to the process or are sold as a by-product, most have no use and must be disposed of on site. A market needs to be developed for rejected fines from the lightweight aggregates industry.

MICA AND SERICITE

Industry Description

Mica is a name applied to a number of complex hydrous minerals in the potassium-aluminum-silicate group with differing chemical composition and physical properties. The principal minerals in this group are muscovite (potassium mica), phlogopite (magnesium mica), biotite (magnesium iron mica) and lepidolite (lithium mica). Muscovite and phlogopite are the most important commercially (9). For commercial purposes, mica is classified broadly as sheet mica and flake and scrap mica (which includes all other forms). Sheet mica is further classified as block mica, film mica, or splittings, according to its thickness.

In 1974, block and film mica was consumed by 13 companies in New Jersey, New York, North Carolina, Pennsylvania, Massachusetts, Ohio and Virginia. Splittings were fabricated into various built-up mica products by 11 companies with 12 plants located in New Hampshire, New York, Ohio, Michigan, Massachusetts, North Carolina, and Virginia. North Carolina was responsible for 56 percent of total scrap and flake production in 1974. The remaining output of scrap and flake mica came from Alabama, Arizona, Connecticut, Georgia, New Mexico, South Carolina and South Dakota (9).

U.S. production of sheet mica in 1974 and 1975 was insignificant. Decline in domestic production has resulted in almost total dependence on imports to meet the demand. The United States, which accounted for 53 percent of world production during 1974, is self-sufficient in the production of scrap and flake mica for grinding purposes. Production statistics for mica appear in Section 1 of this report.

Electrical and electronic industries use the most sheet mica, predominantly in the form of built-up mica from splittings. Most of the block and film mica is consumed in the fabrication of vacuum tube spacers. Other uses include high-pressure steam boilers, marker dials for navigation compasses, optical instruments, pyrometers, thermal regulators, lamp chimneys, microwave windows, and hair-dryer elements.

Scrap and flake mica are generally processed into ground mica for various end uses in: gypsum plasterboard cement, rolled roofing and asphalt shingles, in the paint industry as a pigment extender, and in the rubber industry as an inert filler. Other uses include decorative coatings on wallpaper and on concrete stucco and tile surfaces; as a coating for cores and molds in metal castings; as an absorbent; and as an ingredient in well-drilling muds.

Primary by-products and coproducts associated with mica-bearing pegmatites are clay, feldspar, and lithium. Other minerals of eocnomic importance found in pegmatites include beryl, spodumene, and tantalite.

Process Description

Sheet mica mines are usually small-scale, hand-sorting operations. Open-pit mining is used when economically feasible, but many mica-bearing pegmatites are mined by underground methods. Presently no significant quantity of sheet mica is mined in the United States (9). Because essentially all of the sheet mica used in the United States is imported and processed by the ultimate user, this report is concerned primarily with the flake and scrap mica industry.

Flake and scrap mica is obtained from open-pit quarries (Figure 20). Bulldozers or draglines remove the overburden ahead of the face. Power-driven equipment such as power shovels, drag pans, and trucks then transport the ore from the deposit to the beneficiation plant. Small amounts of scrap mica also occur as a by-product of mining, trimming, and fabricating sheet mica. The three methods used to process the ore are dry grinding, wet grinding and wet beneficiation (39).

In dry grinding facilities, ore from the mine is initially processed through both coarse and fine screens. Then it is fragmented, dried, and sent to a hammer mill. In facilities that process scrap and flake mica, the feed is sent directly into the hammer mill. In wet and dry grinding facilities, the milled product passes through a series of vibrating screens to separate the product into various sizes for bagging. Ground mica yield from beneficiated scrap is 95 to 96 percent.

In a typical wet grinding facility, scrap and flake mica is batch-milled in a water slurry. When the bulk of the mica has been ground to the desired size, the charge is washed from the mill into a decant tank where gritty impurities sink. The ground mica is dewatered by centrifuging and steam drying, and the final product is obtained by screening on enclosed multiple-deck vibrating screens. It is then bagged for shipment.

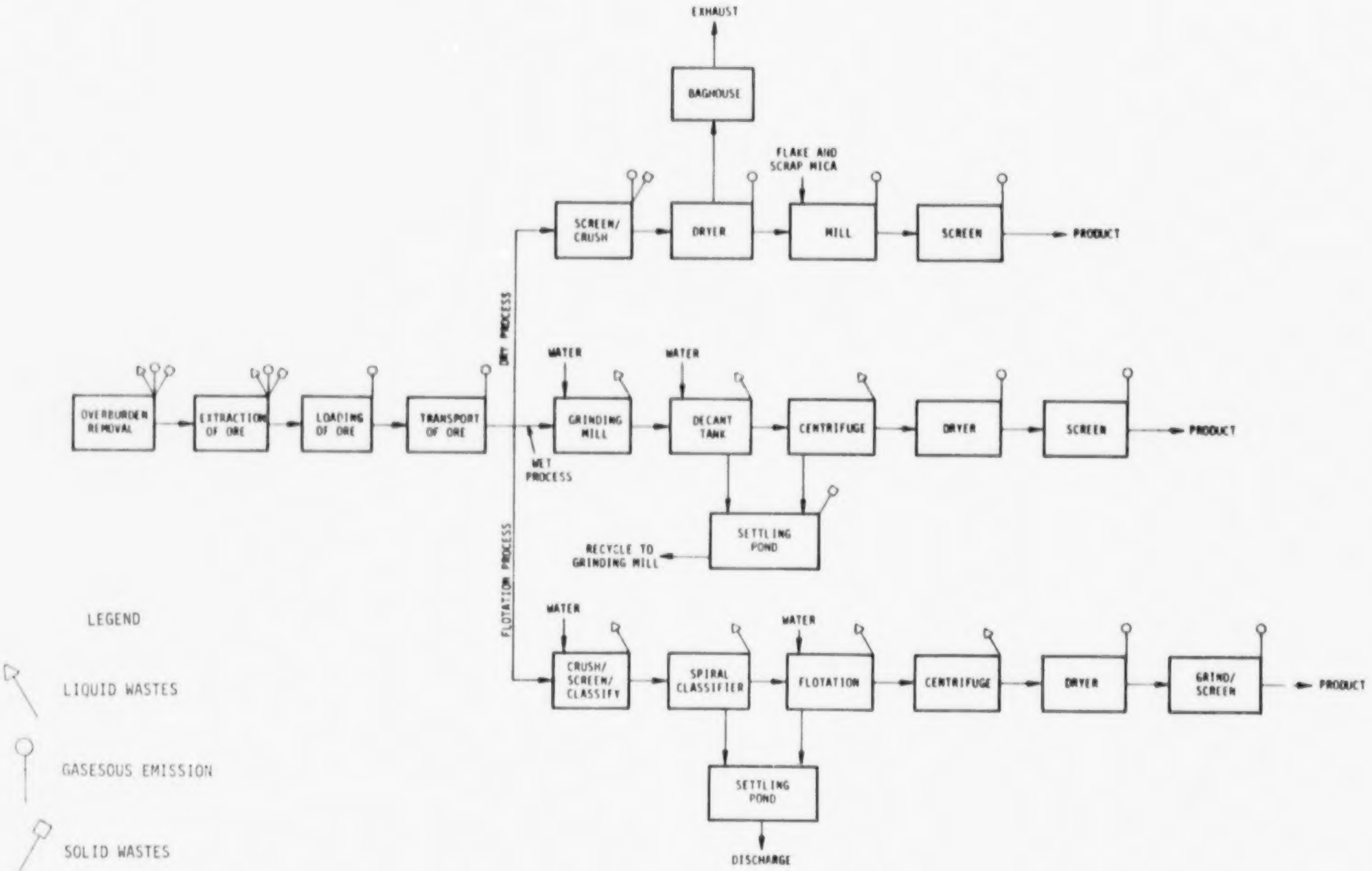
EXHAUST
BAGHOUSE
FLAKE AND SCRAP MICA
SCREEN/ CRUSH
DRYER
MILL
SCREEN
PRODUCT
DRY PROCESS
WATER
WATER
OVERBURDEN REMOVAL
EXTRACTION OF ORE
LOADING OF ORE
TRANSPORT OF ORE
GRINDING MILL
DECANT TANK
CENTRIFUGE
DRYER
SCREEN
PRODUCT
WET PROCESS
SETTLING POND
RECYCLE TO GRINDING MILL
FLOTATION PROCESS
LEGEND
WATER
WATER
LIQUID WASTES
GASESOUS EMISSION
SOLID WASTES
CRUSH/ SCREEN/ CLASSIFY
SPIRAL CLASSIFIER
FLOTATION
CENTRIFUGE
DRYER
GRIND/ SCREEN
PRODUCT
SETTLING POND
DISCHARGE

Figure 20. Mining and beneficiating of mica and sericite.

In the wet beneficiation process, ore from the mine is crushed, screened, and classified to separate the mica from the gangue. This process requires large amounts of water and recovers only about 50 percent of the mica from the ore (60). The ore is sent next to spiral classifiers that separate large mica flakes from the waste sands. The fine sand and clays are deslimed, conditioned, and sent to the flotation section for mica recovery. The mica concentrate recovered by flotation is centrifuged, then fed to a rotary dryer. After the dryer discharge is ground and screened, it is ready for shipment.

Waste Streams

Table 18 presents a summary of multimedia wastes from mining and beneficiating mica and sericite. The following paragraphs explain in more detail the various air, liquid, and solid wastes associated with this industry.

Air Emissions--

Fugitive dust is the principal pollutant discharged from open-pit mining. The dust contains mica, quartz and other minerals (60).

Particulate emissions also result from the screening, crushing, drying, and milling operations in the dry process. Quantitive data on these emissions are not available, however.

Sources of air emissions in the wet process and the flotation process are few since the processes are carried out in the presence of water. The only sources of particulate emissions are the dryer and the screen.

Liquid Wastes--

Runoff produces wastewater from open-pit mining; however, no data are available regarding this effluent.

The dry process produces no wastewater discharges.

Water-use data from two wet-process facilities indicate usage of 4.9 and 125 kiloliters per megagram of product, respectively. At the former facility, about 80 percent of the water is makeup water and the remainder is recycled water from the decanting and dewatering operations. At the latter facility, 1500 liters of makeup water is used per megagram of product, and the remainder is recycled from the settling pond (39). The waste load from these facilities consists of mill tailings, thickener overflows, and wastes from the dewatering units.

The amount of water consumed by facilities with a flotation process depends upon the quantity and type of clay material in

TABLE 18. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF MICA AND SERICITE

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal	Fugitive particulates	N.A.	Overburden removal	N.A.	N.A.	Overburden removal	Waste rock	N.A.
Ore extraction			Ore extraction			Ore extraction		
Ore loading			Grinding mill	N.A.	N.A.	Screening/ crushing	Rock	N.A.
Ore transport			Decant tank			Settling pond	Sludge	N.A.
Screening/ crushing	Particulates	N.A.	Centrifuge	N.A.	N.A.			
Dryer	Particulates	N.A.	Crush/ screen/ classify	N.A.	N.A.			
Mill	Particulates	N.A.						
Screening	Particulates	N.A.	Spiral classifier	N.A.	N.A.			
			Flotation	N.A.	N.A.			
			Centrifuge	N.A.	N.A.			

N.A. - Not available.

the crude ore. The range of consumption is 69.5 to 656 kiloliters per megagram of product (39). No data are available on raw waste from these facilities.

Solid Wastes--

Overburden and waste rock are the major solid waste problems from mica mining.

In the dry process, screens (the only source of solid wastes), generate rocks and boulders.

In the wet process, the settling pond produces solid waste in the form of sludge.

Control Technology

Control technologies as applied in the mining and beneficiation of mica and sericite are explained in the following paragraphs.

Air Emissions Control--

Fugitive dust from open-pit mining and processing is controlled by wetting and spraying with water.*

Plant process sources (screening, crushing, and drying) are hooded, and emissions are ducted to control devices such as fabric filters or scrubbers.*

Liquid Waste Controls--

The raw waste stream from the wet process is collected in surge tanks. A portion of the decanted water is recycled to the process, and the remainder is pumped to a treatment facility. The treatment facility usually consists of settling ponds, which sometimes use polymers as a settling aid. Some of the treated water from the pond is recycled and some is discharged (39).

Raw waste from the flotation process also is pumped to a settling pond. Supernatant from the pond usually is recycled to the facility; however, the pond is allowed to discharge during exceptionally heavy rainfall (39).

Solid Waste Control--

Some of the overburden and waste rock from the mining and processing operations is used to build berms for settling ponds and the rest is piled on or off site.

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*Telephone conversation between Vijay Patel of PEDCo and Bill Anderson, North Carolina Air Pollution Control Agency, Ashville, North Carolina. April 1977.

Because the amount collected is small, sludge is allowed to accumulate in the settling ponds.*

Conclusions and Recommendations

Very little mica and sericite are mined in the United States, so the environmental impact from this industry is minor. Conventional state-of-the-art techniques are used to control all major pollutants.

Large quantities of makeup water are used in the flotation process, and most of it is discharged after treatment in settling ponds. An investigation might determine the feasibility of recycling this treated effluent.

Fugitive dust cannot be controlled by wetting with water when the ambient temperature falls below freezing, therefore, alternative wetting agents need to be investigated.

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*Telephone conversation between Vijay Patel of PEDCo and Bill Anderson, North Carolina Air Pollution Control Agency, Ashville, North Carolina. April 1977.

SECTION 5

NONFERROUS METALS

ALUMINUM

Industry Description

The principal aluminum ore, bauxite, consists mainly of gibbsite [$Al(OH)_3$], boehmite [AlO(OH)], and diaspore ($Al_2O_3 \cdot H_2O$). The aluminum content in bauxite is enriched by removal of most of the other elements in the parent rock, primarily by dissolution of the water-soluble minerals. Impurities in the ore include iron oxide, aluminum silicate, titanium dioxide, quartz, and compounds of phosphorous, vanadium, and gallium. Bauxite is not regarded as a distinct mineralogical species; however, it has become customary to use this term for rocks in which alumina (aluminum oxide material) predominates (66).

The United States produces and consumes the most aluminum products, even though we are currently forced to import about 90 percent of the bauxite from the less industrialized nations where most of the reserves are found. Statistics indicate that we mined approximately 12 percent of our usage in 1973 (10). This percentage will decline as the demand for bauxite rises and domestic mining volume remains stable. Although domestic reserves of bauxite total about 50 million tons, supply is relatively inelastic because most of this ore is of poor quality. Also, only an estimated 20 percent of these reserves is considered now economically recoverable with the present extraction and processing methods (10).

Arkansas produces most of the domestic bauxite (90%); Alabama and Georgia contribute lesser amounts. Small deposits also are found in northwestern Oregon, but the quality is poor so the ore is not mined.

About 88 percent of the bauxite mined is used to produce aluminum. The rest is used for nonmetal purposes such as abrasives, refractories, and numerous aluminum compounds.

Aluminum metal applications generally fall into six major categories: transportation, construction, electrical equipment, containers and packaging, consumer durables, and mechanical equipment. The widespread uses within these categories are well known.

Much of the domestic gallium supply is derived from the processing of bauxite into alumina. Section 1 of this report presents production statistics for aluminum and associated metals.

Process Description

Although underground mining is common in Europe and the USSR, the open-pit method is used to mine 90 percent of the bauxite in the United States. The remaining 10 percent comes from the underground Hurricane Creek Mine in Arkansas. Figure 21 shows a composite flow diagram of bauxite mining and beneficiating.

The stripping ratios of open-pit bauxite mines in the United States run as high as 13 meters of overburden to 1 meter of ore. Some surface pits in Arkansas have reached depths of about 60 meters (10). These parameters are believed to represent the extremes of current economic limits for mining large ore deposits.

Overburden is removed by conventional methods--draglines, shovels, and haulers. The next step usually involves loosening the bauxite by blasting with low-strength dynamite (67). Sometimes blasting is necessary only to loosen the hardcap that comprises the top few feet of the deposit.

Front-end loaders and dump trucks haul the ore to the processing plant, where it is weighed, unloaded onto a stockpile, and sampled for laboratory testing. After the quality of the load is determined, it is transferred to a second stockpile for feeding into the plant. These uncovered stockpiles often occupy large areas.

Crushing is common to all bauxite processing. The steps following the crushing, however, depend on the makeup of the ore and vary widely. Most bauxite beneficiation involves only crushing, washing, and drying operations. More costly techniques are rarely required. Moreover, most impurities such as iron, silicon, and titanium are often too finely dispersed in the bauxite to be readily separated by physical methods. Many bauxite ores are upgraded, however, by washing or wet screening to remove sand and some of the clay minerals. Heavy media separation and jigging are sometimes used to separate the iron minerals. In Arkansas, siderite ($FeCO_3$) has been removed by spiral concentrators and magnetic separators (10).

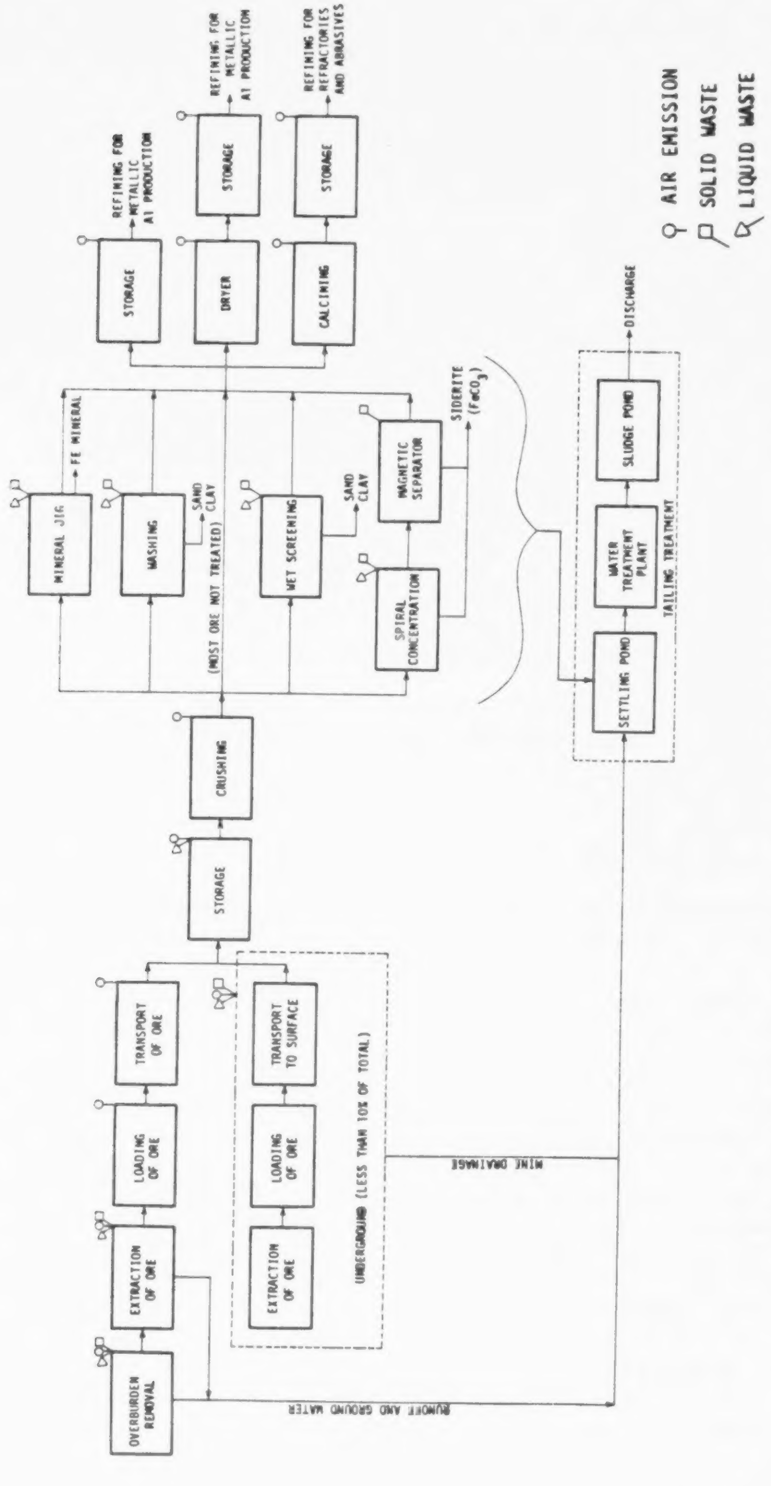
OVERBURDEN REMOVAL
EXTRACTION OF ORE
LOADING OF ORE
TRANSPORT OF ORE
EXTRACTION OF ORE
LOADING OF ORE
TRANSPORT TO SURFACE
UNDERGROUND (LESS THAN 10% OF TOTAL)
RUNOFF AND GROUND WATER
MINE DRAINAGE
STORAGE
CRUSHING
(MOST ORE NOT TREATED)
MINERAL JIG
FE MINERAL
WASHING
SAND CLAY
WET SCREENING
SAND CLAY
SPIRAL CONCENTRATION
MAGNETIC SEPARATOR
SIDERITE ($FeCO_3$)
STORAGE
REFINING FOR METALLIC Al PRODUCTION
DRYER
STORAGE
REFINING FOR METALLIC Al PRODUCTION
CALCINING
STORAGE
REFINING FOR REFRACTORIES AND ABRASIVES
SETTLING POND
WATER TREATMENT PLANT
SLUDGE POND
TAILING TREATMENT
DISCHARGE
AIR EMISSION
SOLID WASTE
LIQUID WASTE

Figure 21. Mining and beneficiating of bauxite.

After necessary physical separation of unwanted impurities, the bauxite may be shipped as is, dried, or calcined. Bauxite contains both free moisture and chemically combined water. For use in refractories and abrasives, it must be calcined to remove the water of hydration. When bauxite is used for other purposes (primarily refining to produce aluminum), only that water is removed which can be justified by lower shiping costs or improved handling characteristics. Most bauxite ores are not dried at the mine site because drying creates serious dust problems during transportation and handling.

If the ore has been dried or calcined, the ore is covered during final storage for protection. Storage is in an open shed which completely controls runoff, but dust may still be a problem during transfer.

Waste Streams

Table 19 presents a summary of multimedia wastes produced by mining and beneficiating bauxite. These include air, liquid, and solid waste emissions, which are covered in more detail in the following paragraphs.

Air Emissions--

Air emissions from the mining and beneficiation of bauxite are mostly fugitive dust. Overburden removal is a variable and potentially large fugitive dust source at surface mines. Dust emitted by this operation vary with the composition and texture of the overburden, its moisture content, excavation procedures, and the type of equipment used. However, the emission rate is most closely related to volume. Overburden-to-ore ratios of 5:1 to 10:1 are common. The economic limit is about 13:1 (10).

A fugitive dust emission factor of 0.02 kilograms per megagram of overburden removed is assumed (65). To convert this emission factor to represent bauxite mining, one must assume an average overburden-to-ore ratio of 7.5:1 (10). This yields a factor of 0.2 kilograms per megagram of bauxite mined.

A published emission factor is not readily available for fugitive dust from the extraction and loading of bauxite ore. To obtain a range, we have assumed that bauxite emissions are somewhere between those of crushed stone and lignite. Published figures for these minerals are 0.01 kilogram per megagram of crushed stone and 0.025 kilograms per megagram of lignite (65). Similar texture characteristics suggest that bauxite is more likely to approximate dry crushed stone.

Again, no published emission factor has been determined for transporting bauxite ore to a storage pile. This operation must

TABLE 19. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF BAUXITE

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal	Fugitive particulates	≈0.2 kg/Mg of ore[a]	Overburden removal	TDS	1.5-3.6 kg/Mg bauxite[h]	Overburden removal	Topsoil, Subsoil, other strata	Up to 13 ft Overburden to 1 ft of Ore - Average 5-10:1[j]
Extraction of ore	Fugitive particulates	.01-.025 kg/Mg of ore[b]		TSS	0.06-0.12 kg/Mg bauxite[h]	Extraction of ore	Gangue	N.A.
Loading of ore	Fugitive particulates	.01-.025 kg/Mg of ore[b]		Total Fe	0.02-0.36 kg/Mg bauxite[h]	Underground operations	Gangue	N.A.
Transport of ore	Fugitive particulates	Dumping - .01-.02 kg/Mg of ore[c] Hauling - .31-.62 kg/km[d]		Total Mn	0.008-0.027 kg/Mg bauxite[h]	Mineral jig	Heavy metals (Fe)	Varies with ore (Sent to tailings pond)
Underground operations	Fugitive particulates from mine ventilation	Negligible		Al	0.008-0.14 kg/Mg bauxite[h]	Washing	Sand-Clay	Varies with ore (Sent to tailings pond)
Ore storage	Fugitive particulates	0.55-.210 kg/Mg in storage[e]		Zn	0.002-0.003 kg/Mg bauxite[h]	Wet screening	Sand-Clay	Varies with ore (Sent to tailings pond)
Ore crushing	Particulates	0.5-4.0 kg/Mg crushed[f]		Ni	0.0008-0.001 kg/Mg bauxite[h]	Spiral concentration	Heavy metals (Fe)	Varies with ore (Sent to tailings pond)
Dryer	Particulates	.06 kg/Mg dried[f]		Sulfate	1.35-1.93 kg/Mg bauxite[h]	Magnetic separator	Magnetics (Fe)	Varies with ore (Sent to tailings pond)
Calcining	Particulates	100 kg/Mg calcined	Extraction of ore	Fluoride	0.0001-0.004 kg/Mg bauxite[h]	Tailings	Tailings	
Product storage	Fugitive particulates	Negligible (in covered sheds)	Underground operations	TDS	0.12-0.18 kg/Mg bauxite[i]			
Tailings	Fugitive particulates	57-88 kg/hm^2 (Dried area only)[g]	Underground operations	TSS	<0.0004-0.06 kg/Mg bauxite[i]			
			Underground operations	Total Fe	0.0003-0.001 kg/Mg bauxite[i]			
			Underground operations	Total Mn	0.0002-0.001 kg/Mg bauxite[i]			
			Underground operations	Al	<0.00001-0.0004 kg/Mg bauxite[i]			
			Underground operations	Zn	<0.000002-0.0003 kg/Mg bauxite[i]			
			Underground operations	Ni	<0.000002 kg/Mg bauxite[i]			

(Continued)

TABLE 19. (Continued)

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
			Underground operations	Sulfate	0.01-0.05 kg/Mg bauxite[i]			
			Underground operations	Fluoride	0.00001-0.0005 kg/Mg bauxite[i]			
			Ore storage	Runoff	N.A.			
			Mineral jig	Heavy metals (Fe)	Varies with ore (Sent to tailings pond)			
			Washing	Sand-Clay	Varies with ore (Sent to tailings pond)			
			Wet screening	Sand-Clay	Varies with ore (Sent to tailings pond)			
			Spiral concentration	Heavy metals (Fe)	Varies with ore (Sent to tailings pond)			
			Tailings	TDS	2.3 kg/Mg bauxite[k]			
			Tailings	TSS	0.008 kg/Mg bauxite[k]			
			Tailings	Total Fe	0.00055 kg/Mg bauxite[k]			
			Tailings	Total Mn	0.0077 kg/Mg bauxite[k]			
			Tailings	Al	0.0017 kg/Mg bauxite[k]			
			Tailings	Zn	0.00022 kg/Mg bauxite[k]			
			Tailings	Ni	0.00055 kg/Mg bauxite[k]			
			Tailings	Sulfate	1.49 kg/Mg bauxite[k]			
			Tailings	Fluoride	0.00097 kg/Mg bauxite[k]			

[a] Ref. 65. Factor for general overburden coverted to typical volume for bauxite.

[b] Ref. 65. Range for crushed rock - lignite, total for extraction and loading.

[c] Ref. 65. Range for dumping crushed rock - lignite.

[d] Ref. 65. Range for hauling crushed rock - lignite.

[e] Ref. 65. Range for active to inactive crushed rock storage.

[f] Ref. 69. Uncontrolled emissions, usually controlled by a baghouse.

[g] Ref. 65. Range for dried tailings in the southeastern U.S.

[h] Ref. 69.

[i] Ref. 69.

[j] Ref. 10.

[k] Ref. 46.

[l] Ref. 46.

N.A. - Not available.

be broken down into two separate tasks - hauling, which is proportional to vehicle miles traveled (VMT), and dumping, which is proportional to the quantity of ore transported. As with ore loading, we have assumed that bauxite falls within the range between crushed rock and lignite, which is 0.31 to 0.62 kilograms per kilometer for hauling (65).

Visits to several underground mines for other minerals led to the assumption that air emissions from underground bauxite mine ventilation are negligible.

Bauxite ore is stored in open piles of about 7500 megagrams each (68). These piles often cover large areas and cause considerable fugitive dust problems. In a mine producing up to 1600 megagrams of ore per day, for instance, storage piles cover about 8 hectares. Again, no emission figures have been published on bauxite ore storage.

Uncontrolled fugitive dust emissions from crushing and conveying vary between 0.5 to 4 kilograms per megagram (69). These emissions, usually controlled by a baghouse, evidence no especially toxic materials. Because particulates fall largely in the coarser size ranges, impacts are judged to be very localized (46).

Ore drying is only done occasionally at the mine site, to eliminate uncombined water. Uncontrolled dust emissions are about 0.6 kilograms per megagram of feed (69). Impacts of these emissions are believed to be intermittent and highly localized.

Calcining of bauxite generates large volumes of airborne particulates, but the economic value of this dust is such that extensive controls are applied to collect it, thus reducing emissions to relatively small quantities. The uncontrolled emission rate is about 100 kilograms per megagram of feed. Control efficiencies range between 70 to 98 percent (69).

The final product is stored in covered sheds, and air emissions from these enclosures are assumed to be negligible.

Emission estimates for dried tailings were developed from the U.S. Department of Agriculture's wind erosion equation (70). This equation was then applied to conditions present in the southeastern part of the United States (65), yielding a range of 5.7 to 8.8 kilograms per hectare per year. When the tailings form a crust, emissions are reduced by 80 percent (65).

Liquid Wastes--

Liquid wastes in bauxite mining and beneficiation are primarily from runoff and groundwater. Of less importance are those resulting from various wet methods of removing sand, clay, and heavy metal impurities. U.S. bauxite mines generally do not require these wet methods. The liquid wastes from these sources are directed to a settling pond where the water is treated by settling and lime neutralization before it is discharged into streams.

The present rate of discharge from bauxite mines averages about 57,000 cubic meters of mine water daily, most of which is from open-pit mining. Underground mining accounts for only a small fraction (29).

The two classes of raw mine drainage generally correspond closely to the mining technique. Open-pit mining drainage is generally acid or ferruginous, with a pH in the range of 2 to 4. Sulfuric acid is formed by oxidation of the pyrite contained in lignite present in the soil overburden. This acid water dissolves other minerals, including those containing aluminum, calcium, manganese, and zinc. Although these same compounds might be formed naturally, mining activity, which disturbs the surface and exposes pyrite to oxygen and water, greatly accelerates the rate of sulfide-mineral dissolution (29). Table 19 presents a typical range of specific pollutants in open-pit drainage.

Drainage from underground mining is characteristically alkaline. Unlike open-pit drainage, which is exposed to sulfide-bearing minerals in the overburden, underground mines receive drainage that has migrated through strata of unconsolidated sands and clays and is not exposed simultaneously to pyrite and oxygen. The pH of this drainage is generally about 7.5 (29). Raw mine water accumulates slowly in underground mines and is pumped to the surface at regular intervals for treatment. Table 19 presents a typical range of specific pollutants in underground mine drainage.

As mentioned, liquid wastes also are generated by various wet methods for removal of impurities. Technologies include wet screening and washing to remove sand and some of the clay minerals, heavy-media separation and jigging to separate iron minerals, and the use of spiral concentrators and magnetic separators to remove siderite (10). Since these methods generally are not necessary, however, no data have been published on the rate of waste generation. When these methods are practiced, this waste goes to tailings and is measured in the average concentrations of the tailings effluent.

A tailings pond can be considered a specific source of liquid wastes, and effluents from this source have been measured. Wastewater sent to tailings ponds presently are being treated only by settling and lime neutralization. In the near future it may be possible to treat tailings by a mobile lime-treatment plant. Typical amounts of specific pollutants released from tailings ponds are given in Table 19.

Solid Wastes--

Solid waste generation resulting from the mining and beneficiation of bauxite come from overburden, gangue, and tailings. The overburden produced in open-pit mining normally is stored in heaps adjacent to the pits and may be used in refilling and recontouring mined-out areas. Because the pyrite in the overburden combines with water and creates an acid soil condition, revegetation proceeds extremely slowly. The concomitant lack of vegetation accelerates the weathering of the overburden, thereby contributing to a liquid waste problem. Because of the large volume of overburden generated (by removal of up to 4.0 meters of overburden per 0.3 meter of ore) the runoff problem can be serious. Generally between 1.5 and 3.0 meters of overburden per meter of bauxite are removed (10).

Once the overburden has been removed, the pyrite content of the bauxite deposit is sufficiently low to make the liquid waste problems associated with gangue appear not to be as serious as with overburden. Pyrite is less abundant because it and other soluble materials have been leached out during the formation of the bauxite deposit. Therefore the environmental impact of gangue produced by bauxite mining is less than that from overburden. No published figures were found from which to estimate the volume of gangue produced per megagram of bauxite mined.

Solid waste is generated by various wet methods of beneficiation. These wastes are transported in liquid form to the tailings pond, where sedimentation and precipitation of the heavy metals occur. No published figures were found to estimate the volume of solid waste tailings formed per megagram of bauxite.

Control Technology

Control technology in the bauxite mining industry is much the same as that used in other mining industries. The following paragraphs explain these controls as applied to air, liquid, and solid waste.

Air Emissions Control--

Overburden removal and ore extraction are among the most variable fugitive dust sources at surface mines. Dust losses from these operations vary with the composition, texture, and moisture content of the material; excavation procedures; equipment employed; etc. A literature search yielded no specific devices for controlling fugitive dust from these sources (65).

Dust is generated by many aspects of the truck-loading operation, but mainly by moving the trucks into position for loading, by scooping up the loose material into a shovel bucket, and by dumping the load from the bucket into the truck bed. The same emission factors apply as those given for overburden removal because no specific control devices were found for loading either.

Watering or oiling the haul roads is used extensively to reduce dust generated from ore transport. A control efficiency of 50 percent is assumed for watering the haul roads. Using portable beneficiation equipment to reduce the length of the haul is another method of reducing emissions.

Visits to several underground mines for other minerals indicate that control of air emissions from underground bauxite mine ventilation is unnecessary.

No information found indicates that any form of dust control presently is applied to the open bauxite ore storage piles. Chemical dust suppressants are on the market that would solve any localized problems, at least on a short-term basis. Control efficiencies of these products are estimated at 50 to 80 percent (71).

Dust emissions from crushing generally are caught in a baghouse. No evidence points to the presence of especially toxic materials, and particulates are believed to fall largely in the coarser size ranges (46). Efficiency of baghouse control is estimated at 99 percent (49).

When bauxite is dried at the mine site, emissions can be controlled adequately by available technology (e.g. baghouses). The presence of highly toxic substances is not anticipated in these emissions; particulates are expected to be in the larger size ranges (46). Control efficiency for a baghouse is estimated at 99 percent when no hygroscopic substances are present (49).

Emissions from calcining bauxite can be controlled by various dry-dust-collection devices such as centrifugal collectors, multiple cyclones, and electrostatic precipitators, or combinations of these controls. Impacts of this dust are judged to be moderate to low, because alumina is not considered to be harmful unless very fine particles (i.e., less than 1 to 5 micrometers) reach the lower respiratory tract. Efficiencies of these devices are estimated to be between 70 to 98 percent (46).

Because calcined and dried bauxite is stored in covered sheds until shipped, the air emission impact during storage is considered negligible.

Air emissions from tailings can be expected only when the tailings pond becomes dry (i.e. when operations have ceased). The intentional or natural formation of crust under these conditions can reduce emissions by as much as 80 percent (69).

Liquid Waste Control--

Water contaminated by runoff from overburden removal and mining can be controlled in three ways. First, precipitation leaches out various pollutants because formerly buried minerals are exposed, and oxygen reacts with the exposed minerals. If this material is reburied, covered with top soil, and revegetated, much of the groundwater and runoff contamination will be eliminated. This technology is practiced in the coal strip-mining industry.

A second method is to treat the contaminated water with lime in a settling pond before releasing it to the environment.

Lime treatment reduces metal content in most metals by more than 90 percent. Sulfate and fluoride content is also reduced. Settling reduces total suspended solids (TSS) by 85 percent, whereas total dissolved solids (TDS) actually increase with lime treatment. Water pumped from underground mines as well as water from various wet beneficiation methods also is lime-treated in settling ponds.

A third method, which reduces the volume of water that must be treated, diverts the groundwater away from the mining area. This is accomplished by a system of dewatering wells, strategically placed, which divert water that would naturally flow into the mine. Details of this method are presented in the literature (43).

Solid Waste Control--

Because of the growing demand for complete land reclamation, it is advisable to segregate the overburden material by removing top soil and other subsoil components suitable for revegetation, storing them separately, and then covering the contoured spoil banks with these two layers during the reclamation process. This procedure greatly increases the ability to revegetate and reclaim the land (72).

Backfilling of the mined-out area or the underground mine is a good disposal method for the solid waste generated by any of the mining processes. Even the tailings can be disposed of by dredging and backfilling.

Estimation of a control efficiency for this type of operation is difficult; however, it is conceivable that all of the solid waste generated could be reburied and revegetated. Product economics and local public demands will probably determine how much is properly reclaimed.

Conclusions and Recommendations

The available techniques of land reclamation and lime treatment of mine runoff are adequate to maintain environmental standards in the bauxite mining and beneficiation industry. Air emissions also can be controlled conventionally.

One promising area of research involves the reduction of the volume of water produced by mining. Ground water control techniques will be required. These techniques are presently being used to increase the stability of open-pit slopes and thereby aid in the economical removal of bauxite. Also, dewatering of the pits enables production to continue when winter rains would normally cause it to be curtailed.

The technique consists of drilling wells in locations around the ore body and pumping out the ground water before it can reach the mine. Locations of wells are determined by techniques common to ground water hyrology. A description of dewatering at three bauxite mines in the Eufaula district in Alabama is contained in Reference 72. Expansion of the use of the technique to minimize the production of acid mine discharge will require investigation of the use of gravity wells and drains as described in Reference 43.

ANTIMONY

Industry Description

Antimony occurs in over a hundred minerals. Sometimes native metallic antimony is found free; however, the most important source of the metal is stibnite (Sb_2S_3). When exposed to the atmosphere, stibnite converts to various oxides. The important oxide minerals are stibiconite ($Sb_3O_6[OH]$), cervantite (Sb_2O_4 or $Sb_2O_3 \cdot Sb_2O_5$), valentenite (Sb_2O_3), senarmontite (Sb_2O_3), and kermasite ($2Sb_2S_3 \cdot Sb_2O_3$). Complex stibnite ores containing lead, copper, silver, and mercury also can be important sources of antimony. When the antimony content is lean, it may be recovered as a by-product (11).

In 1974 the United States consumed an estimated 26 percent of the world's production of primary antimony, while producing less than 1 percent. The bulk of the demand is met either by scrap recovery or imports. Scrap recovery comes primarily from batteries and provides approximately 50 percent of the U.S. supply. No change is expected in this supply-demand relationship in the foreseeable future (11).

Virtually all U.S. antimony that is recovered from domestic ores comes from deposits as a by-product of silver, lead, copper, and zinc ores. Lead-silver mines in the Idaho Coeur d' Alene area produce the bulk of the mined antimony in the United States. Idaho, Montana, and Nevada supply over 50 percent of the domestic primary antimony. Antimony recovered at three domestic lead refineries supplied the remainder (11).

Antimony is classified chemically as a nonmetal or metalloid, although it has metallic characteristics in the elemental state (11). It is used primarily as an alloy in lead and other metals. In 1974 nearly half of the total demand was used in storage batteries. It also is used in power transmission and communication equipment, type metal, solder, and ammunition. Antimony, in its nonmetallic form, is used industrially in fire retardant and industrial chemicals, rubber and plastic products, and ceramic and glass products (11).

Because most of the world's supply of antimony is concentrated in the People's Republic of China, production in the United States will continue to be dictated by domestic supply rather than demand. Section 1 present production statistics for antimony and associated metals.

Process Description

Only one U.S. mine operates solely for the recovery of antimony ore (29). This northwestern Montana mine applies both underground and open-pit methods; however, most of the ore is mined underground (64). Figure 22 shows a composite flow diagram for the mining and beneficiating of antimony ores.

Several mines in the United States produce antimony as a coproduct or by-product of other ores. Mining methods at those mines that produce antimony only as a minor constituent are designed for recovery of the principal metal (lead, silver, or gold). The typical small mine is entered by shallow shaft or short adit, developed by drifting in the vein (11).

Emissions at mines, where antimony is a by-product, are not related to the mining of the antimony. Although it is generally economical to separate the antimony from the concentrate, the economics of mining the ore are independent of the presence of antimony. Also, emissions associated with the separation of the antimony to form a concentrate occur in the refining stages of the primary metal production. Therefore, the emissions from the mining and beneficiation of the complex ores that contain antimony are not considered here. Process descriptions and emissions for these ores are covered in their respective sections, (i.e., silver, gold, copper, lead, zinc).

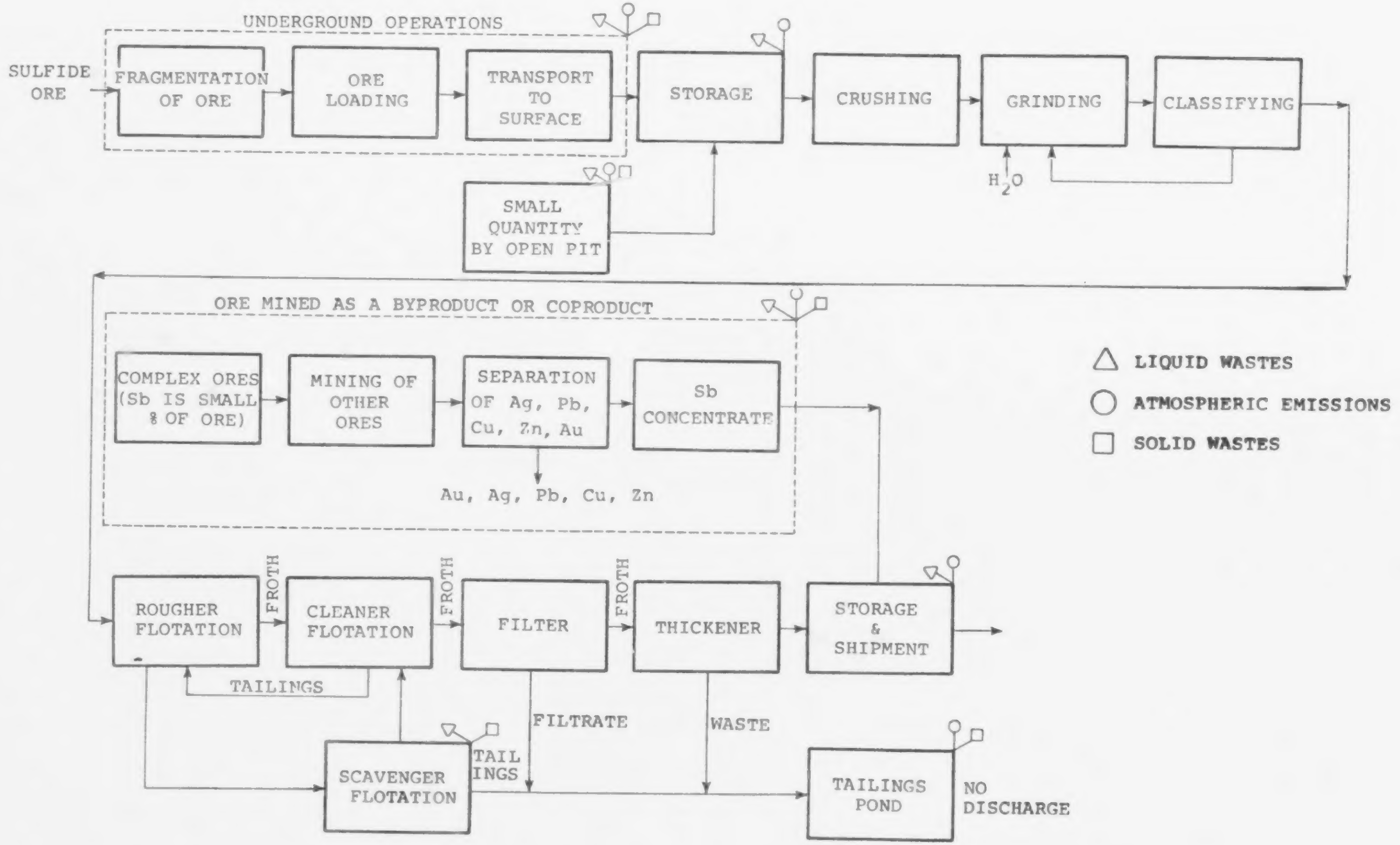
UNDERGROUND OPERATIONS
SULFIDE ORE
FRAGMENTATION OF ORE
ORE LOADING
TRANSPORT TO SURFACE
STORAGE
CRUSHING
GRINDING
CLASSIFYING
H_2O
SMALL QUANTITY BY OPEN PIT
ORE MINED AS A BYPRODUCT OR COPRODUCT
COMPLEX ORES (Sb IS SMALL % OF ORE)
MINING OF OTHER ORES
SEPARATION OF Ag, Pb, Cu, Zn, Au
Sb CONCENTRATE
Au, Ag, Pb, Cu, Zn
△ LIQUID WASTES
○ ATMOSPHERIC EMISSIONS
□ SOLID WASTES
ROUGHER FLOTATION
FROTH
CLEANER FLOTATION
FROTH
FILTER
FROTH
THICKENER
STORAGE & SHIPMENT
TAILINGS
SCAVENGER FLOTATION
TAIL INGS
FILTRATE
WASTE
TAILINGS POND
NO DISCHARGE

Figure 22. Mining and beneficiating of antimony from sulfide and complex ores.

Antimony is considered a coproduct of silver in some complex deposits in Idaho that also contain copper, lead, and gold. Silver is the primary metal mined at these underground mines, followed by copper (64). Final separation of the antimony is accomplished by leaching with Na_2S and electrolysis in the refining stage, not in beneficiation. Processes and emissions are covered later in this section.

In 1974, the one U.S. mine worked solely for antimony produced about 7000 megagrams of ore containing a little over 200 megagrams of antimony. Although this mine used the single-bench, open-pit method, most U.S. ores mined for their antimony content are recovered from underground methods.

Ore is hauled by truck to the primary crushers. It is crushed, wet-ground, and classified before being sent to the rougher flotation process. Oversized ore is returned by the classifier to the grinder for regrinding.

Concentration of the antimonial ore is accomplished by froth flotation. Antimony-rich rises in the froth in each of three flotation steps. The concentrate then is filtered and sent to a thickener for final concentration before shipment.

Waste Streams

Table 20 presents a summary of multimedia wastes from the mining and beneficiating of antimony ores, and the following paragraphs explain these air, liquid, and solid wastes in more detail.

Air Emissions--

Few air emissions are associated with the mining and beneficiating of antimony ore because it is mined underground and beneficiated by wet techniques. Air emissions from mine ventilation are negligible.

No information was found on air emissions emanating from ore storage, ore crushing, or concentrate storage during antimony beneficiation.

An emission estimate for dried tailings was developed from the U.S. Department of Agricultural wind erosion equation (70). When applied to conditions present in the Pacific northwest mining area, this equation yielded a value of 28.5 kilograms per hectare. If the tailings form a crust, emissions can be reduced by as much as 80 percent (65).

TABLE 20. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF ANTIMONY ORES[a]

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Underground operations	Fugitive particulates from mine ventilation	Negligible	Underground operations	Sb, Fe, Zn, Ag, Hg, Pb	No discharge presently, possible in the future	Underground operations	Gangue	97% of ore is gangue; most backfilled; under 130 kg/Mg of ore remaining.^{e}
Ore storage	Fugitive particulates	N.A.	Ore storage	Runoff	N.A.	Scavenger flotation	Tailings	N.A.
Ore crushing	Particulates	N.A.	Scavenger flotation	pH	8.3^d	Tailings pond	Tailings	N.A.
Product storage	Fugitive particulates	N.A.	Filter	TSS	7.48 kg/Mg of ore^d			
Tailings pond	Fugitive particulates	28.5 kg/hm^2 (dried area only)	Thickener	COD TOC Fe Pb Sb Zn Cu Mn Mo	0.0322 kg/Mg of ore^d 0.059 kg/Mg of ore^d 0.141 kg/Mg of ore^d 0.00097 kg/Mg of ore^d 0.48 kg/Mg of ore^d 0.033 kg/Mg of ore^d 0.009 kg/Mg of ore^d 0.003 kg/Mg of ore^d <0.0015 kg/Mg of ore^d			
			Product storage					

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[a] For more complete derivation of factors see Sections 6.3.1-6.3.3.

[b] Ref. 65. Range for dried tailings in the Pacific Northwest mining area.

[c] Ref. 29.

[d] Ref. 29.

[e] Ref. 64.

Liquid Wastes--

Presently no liquid wastes are created in the one underground antimony mine in the United States (29). However, more extensive development of this mine could create a discharge. Such a discharge probably would contain arsenic, iron, antimony, zinc. No information was found concerning runoff from storage piles of antimony ore.

Forty-nine separate constituents were measured in the raw discharge from an antimony flotation mill (29). Table 21 presents the major waste constituents from this mill. These figures represent combined discharges from the flotation tanks, the filter, and the thickener.

No information was found on runoff from product storage. Also, although 286 to 343 cubic meters per day of liquid waste was discharged from the flotation mill to the tailings pond at the mine studied, no discharge occurred from the pond.

Solid Wastes--

Solid waste generated by the mining and beneficiation of antimony ores consists of gangue from underground operations and tailings from the flotation mill. Nothing indicates that any of the waste is particularly hazardous.

Reference 64 contains the only estimate found regarding the solid waste generated at the one U.S. antimony mine. Ninety-seven percent of the ore is gangue, but most of this is backfilled into the mine. At the one mine, which extracts about 7000 megagrams of ore per year, the quantity of solid waste remaining after backfilling is 900 megagrams (64).

Control Technology

Control problems in antimony mining are similar to those in other mining industries. Applicable controls include settling, lime precipitation, sulfide precipitation, and backfilling.

Air Emissions Control--

Because antimony is mined undergound and beneficiation is by wet methods, this industry generates very few air emissions. The crushing operation is a possible source of emissions and some fugitive dust could occur. Particulate emissions from crushing can be controlled by any of several conventional methods.

Air emissions from tailings occur only when the tailings pond becomes dry, (i.e. when operations have ceased). A crust, formed either intentionally or naturally, can reduce these emissions as much as 80 percent (65).

TABLE 21. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF BERYLLIUM ORE

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal	Fugitive particulates	N.A.	Crushing/ grinding/ screening	N.A. (spills)	N.A.	Overburden removal	Gangue	Overburden ratio 5:1[b]
Extraction of ore	Fugitive particulates	N.A.	Acid leaching	TDS Sulfate Fluoride Aluminum Beryllium Zinc	18,380 mg/ℓ[a] 10,600 mg/ℓ[a] 45 mg/ℓ 552 mg/ℓ 36 mg/ℓ 19 mg/ℓ	Extraction of ore		
Solvent extraction	Vapor from alkaline berylate solution	N.A.						
			Solvent extract-tion	N.A.	N.A.			

[a] Ref. 29.

[b] Meeting between Jack Greber of PEDCo and Ken Poulson, Brush Wellman, Inc., Delta, Utah. December 1976.

N.A. - Not available.

Liquid Waste Control--

Presently, there is little runoff or mine drainage associated with the mining of antimony. Should a discharge develop, it can be controlled by settling, lime precipitation, or sulfide precipitation. Settling and lime precipitation should reduce pollutant levels in the following manner: TSS, 20 percent; arsenic, 28 percent; iron, 33 percent; antimony, 16 percent; zinc, 33 percent. Another recommended treatment is additional sulfide precipitation of the effluent, but control efficiences are not known (29).

Solid Waste Control--

As alluded to earlier, the antimony content of the ore from the only antimony mine in the United States is 3 percent. Therefore, of the approximately 7000 megagrams of ore mined per year, almost 6800 megagrams would initially be waste. All but about 900 megagrams of this waste is returned to the mine for backfill; therefore control efficiency is about 87 percent (64).

Conclusions and Recommendations

Pollution problems from the mining of antimony in the United States are insignificant because of the small quantities involved.

Air emissions, liquid wastes, and solid wastes are all small or nonexistant in both mining and beneficiating processes. Hence, no areas of research are recommended for antimony.

BERYLLIUM

Industry Description

Beryllium occurs as an essential constituent in approximately 40 minerals and an occasional constituent in 50 others (73, 74). Beryl, $Be_3Al_2Si_6O_{18}$, and bertandite, $Be_4Si_2O_7(OH)_2$, are the principal beryllium minerals in the United States. Beryl is commonly a constituent of pegmatites, and coarse-grained pegmatites yield most of the beryl used in industry. Other commonly known beryllium minerals include phenacite, barylite, and chrysoberyl.

The beryllium industry is relatively small compared with most of the other nonferrous industries. As of 1975, the United States had only two major beryllium producers (12). One company in Utah mines bertrandite and converts it to an impure beryllium hydroxide at a plant near the town of Delta. The other company imports beryl for conversion to beryllium materials at plants in Reading and Hazelton, Pennsylvania. The U.S. production of pegmatitic beryl now comes from the Black Hills area in South

Dakota and from northern Colorado, but deposits are present also in the Appalachians and in the mountains of New Mexico and Wyoming (75). Pegmatites are not usually mined for their beryl content (12). Beryl is generally recovered as a coproduct of mining other pegmatite minerals such as feldspar, mica, lithium minerals, columbite, tantalite, and cassiterite. Deposits of these minerals yield varying quantities of cobbed ore broken from beryl. Production statistics for beryllium are shown in Section 1 of this report.

Beryllium is used as a metal, as an alloying agent, and as an oxide. Beryllium metal is used when a high stiffness-to-weight ratio is required, as in the aerospace industry (e.g. space optical devices, X-ray windows, aircraft brakes, and missile components). It is used also in nuclear applications when a low thermal-neutron absorption and a high-neutron-scatter cross section are required.

More than half of the beryllium is consumed in beryllium-copper alloy products, to which beryllium imparts strength, hardness, and resistance to fatigue, corrosion, and wear. Molds fabricated from beryllium-copper give plastic furniture the wood-grain appearance. The variety of markets for beryllium-copper alloys increases constantly and now includes the business machine, appliance, transportation, and communication industries. These alloys are used in electrical and electronic systems for connectors, sockets, switches, and temperature- and pressure-sensing devices to facilitate miniaturization and to provide reliability and long service life. Beryllium oxide ceramics are used in parts for lasers and microwave tubes, and in semiconductors.

Process Description

Beryllium ore currently is mined on a large scale at only one domestic operation. The bertrandite at this mine contains approximately 1 percent beryllium and occurs erratically in altered tuff that lies close to the surface. It is recovered by open-pit methods (29). The average stripping ratio is 5:1.*

The ore is mined by conventional open-pit mining techniques. (Figure 23 illustrates the flow sheet for mining and benefication of beryllium.) The ore is blasted free, extracted, and hauled by truck to temporary storage piles. During storage it is blended with different grades of ore to make it homogenous, then shipped to a mill approximately 84 kilometers away.

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*Meeting between Bob Amick and Jack Greber of PEDCo and Ken Poulson, Bruce Wellman, Inc., Delta, Utah. December 1976.

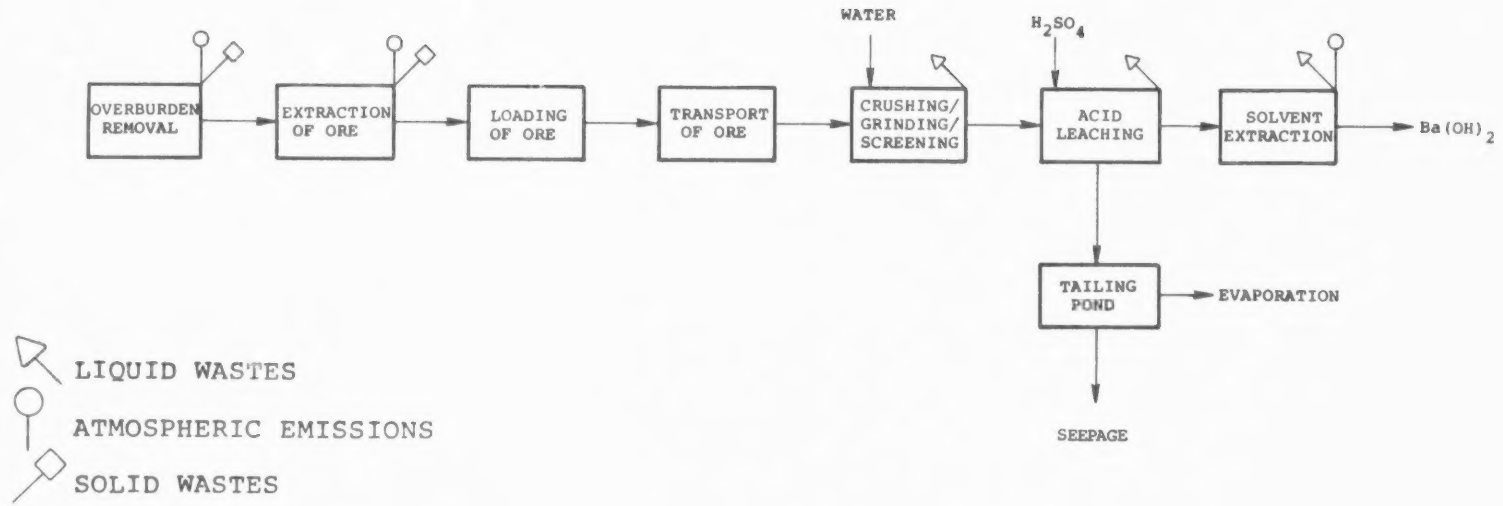
OVERBURDEN REMOVAL
EXTRACTION OF ORE
LOADING OF ORE
TRANSPORT OF ORE
WATER
CRUSHING/ GRINDING/ SCREENING
H_2SO_4
ACID LEACHING
SOLVENT EXTRACTION
$Ba(OH)_2$
TAILING POND
EVAPORATION
SEEPAGE
LIQUID WASTES
ATMOSPHERIC EMISSIONS
SOLID WASTES

Figure 23. Mining and beneficiating of beryllium ore.

To free the bertrandite minerals from associated gangue, the ore is wet-crushed, wet-ground, and wet-screened to a thixotropic slurry in preparation for a leaching step. The ore slurry then is leached in a 10 percent sulfuric acid solution to put the beryllium in solution and separate it from the insoluble gangue. After leaching, solids are separated and washed by countercurrent displacement in a series of thickeners.

Beryllium sulfate is selectively extracted using an organic chelating agent, di-2-ethylhexyl phosphoric acid in a kerosene diluent. The extracted beryllium in the organic solvent is separated from the spent leach liquor (raffinate) in settling tanks. The following then occurs in subsequent steps: the organic solution containing the chelated beryllium ions (free of impurities) is remixed with an alkaline stripping solution to produce a solution containing an alkaline berylate compound; the stripped organic phase is recycled; beryllium hydroxide is precipitated from the alkaline berylate solution by boiling and is separated from the filtrate by centrifuging and filtering; and the alkaline filtrate is recycled (76).

Waste Streams

Table 21 presents a summary of multimedia wastes from the mining and beneficiating of beryllium. The following paragraphs cover the various air, liquid, and solid wastes in more detail.

Air Emissions--

Very little air pollution is generated from the mining and beneficiation of bertrandite. No dust problems are associated with open-pit mining of the ore because it contains an average of 18 percent moisture (range 16 to 22%) (75). However, some fugitive dust is emitted from the waste dump, access roads, and blasting.

Since all beneficiation processes are wet, dust problems are minimized. The solvent extraction process generates a nontoxic vapor from boiling alkaline berylate solution (76).

Liquid Wastes--

All water within the mine site is either evaporated or percolates into the ground because the climate of the region is arid.

Crushing, grinding, and screening do not generate any liquid wastes per se because the ore slurry goes on to the leaching operation, however, spills are possible.

The acidic residues of leaching obtained from the thickeners are combined with alkaline waste solutions generated in another part of the plant to form a slurry with a pH of 8 to 10 (75). The waste stream from the leaching process is exceptionally high in dissolved solids (18,380 mg per liter), consisting largely of sulfate (10,600 mg per liter), fluoride (45 mg per liter), aluminum (552 mg per liter), beryllium (36 mg per liter), and zinc (19 mg per liter) (29). This waste stream could be considered potentially hazardous (77).

Liquid wastes from the solvent extraction process include spent leach liquor (raffinate), spills of organic solution in the extraction circuit, and spills of alkaline stripping solutions (75).

Solid Wastes--

Considerable amounts of gangue are generated from open-pit mining of bertrandite ore. The stripping ratio is 5:1.*

Control Technology

Control technologies applied in the mining and beneficiation of beryllium are explained in the following paragraphs.

Air Emissions Control--

Since no significant air emissions are generated, control devices are not required.

Liquid Waste Control--

The slurry of solids from the acid leaching process are discharged to a waste storage lagoon. Water is removed from the pond by natural evaporation and, possibly percolation into the subsurface.

Solid Waste Control--

Waste rock (spoils) from open-pit mining is used in land reclamation (12).

Conclusions and Recommendations

The beryllium industry in this country is relatively small. The proprietary nature of some of the processes and the fact that only one mine is currently operating in this country make a complete environmental assessment impossible.

The wastewater and solid wastes at this mine appear to be under control. Wastewater is impounded and allowed to evaporate, and the solid waste is blended into the topography during reclamation. Air pollution poses no significant problem. The only problem that might be worthy of further research is the extent to which impoundments prevent leakage and the resulting leaching into groundwater.

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*Meeting between Bob Amick and Jack Greber of PEDCo and Ken Poulson, Bruce Wellman, Inc., Delta, Utah. December 1976.

COPPER

Industry Description

The principal copper-bearing minerals are chalcocite (Cu_2S), chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), chrysocolla ($CuSiO_3 \cdot 2H_2O$), azurite [$2CuCO_3Cu(OH)_2$], and malachite [$CuCO3Cu(OH)_2$]. Copper is most often combined chemically with sulfur, but frequently with iron or arsenic, and sometimes with other elements (78). Copper ore also provides significant quantities of by-products and coproducts such as gold, silver, molybdenum, selenium, tellurium, and rhenium (13).

In 1974 the United States led the world in producing and consuming copper. Twenty-five mines accounted for 93 percent of the U.S. output; the five largest mines produced 41 percent and four companies accounted for 64 percent (13). The principal copper-producing states in 1974 were Arizona (54 percent of total U.S. production), Utah (14 percent), New Mexico (12 percent), Montana (8 percent), Nevada (5 percent), and Michigan (4 percent). Most of the remaining 3 percent came from Missouri and Tennessee. Production statistics appear in Section 1 of this report.

The most copper goes into the manufacture of electrical equipment and supplies. Electric motors, power generators, motor-generator sets, dynamotors, fans, blowers, industrial controls, and related apparatus perform better when copper is used in their manufacture.

Because they are corrosion-resistant, copper and its alloys have many uses in the construction industry. Construction materials for roofing and plumbing, and brass and bronze for decorative and utilitarian items require significant quantities of copper.

Copper is also consumed by the following applications in the production of nonelectrical machinery, household and commercial air-conditioning, and farm machinery, in automobile manufacture, railroad transportation, airplane manufacture, and marine parts, in watches, clocks, microscopes, projectors, jewelry, and coinage, and for miscellaneous uses such as chemicals and inorganic pigments.

Process Description

Both open-pit and underground methods are used to mine various types of copper deposits. Open-pit mining accounts for nearly 80 percent of the copper ore mined in the United States (13). Most ore deposits contain less than one percent copper. The copper content of the ore is 15 to 30 percent after concentration.

Open-pit mining involves the removal of ore from deposits at or near the surface by a series of operations consisting of drilling blast holes, blasting the ore, loading the broken ore onto trucks or rail cars, and transporting it to the concentrators (Figure 24). Occasionally blasting is not required, and ore is ripped loose by bulldozers. Barren surface rock overlying the deposit must be removed to uncover the ore body. Such overburden may go as deep as 150 meters (76).

Underground mining involves the removal of ores from deep deposits by a number of techniques. The selection depends on the characteristics of the ore body. The two main methods are caving and supported stoping. Block caving is used in large, homogeneous, structurally weak ore bodies, and the stop-sluicing caving method for smaller and more irregular ore bodies. Supported stoping methods are used to mine veins and horizontal deposits of copper ore.

Following extraction, ore and overburden are loaded by power shovels onto rail cars or trucks and hauled to the mill. Some mines use belt conveyors and skip ways to transport the ore. Large underground mines use rail haulage, hoisting facilities, and shuttle cars.

Beneficiation of copper ores may be accomplished by physical-chemical separation of minerals from the gangue material (used for copper sulfide ores) or by hydrometallurgical (leaching) methods (oxide and mixed oxide-sulfide ores). Table 22 shows the various concentrating alternatives used in copper recovery.

The bulk of the United States copper comes from sulfide ores. Typical processing steps for sulfide ores are crushing, grinding, classification, flotation, and dewatering. The ore enters the mill and is discharged over a grizzly into a gyratory crusher. Most of the crushing is done in three steps (79). The first gyratory crusher reduces the ore to a 15.2 to 22.9 centimeter size. Following screening, gyratory or cone-type crushers further crush the oversized pieces to yield a 2.54 to 5.1 centimeter product. Water and lime are mixed with the ore, and fine grinding takes place in rod and/or ball mills. Primary and

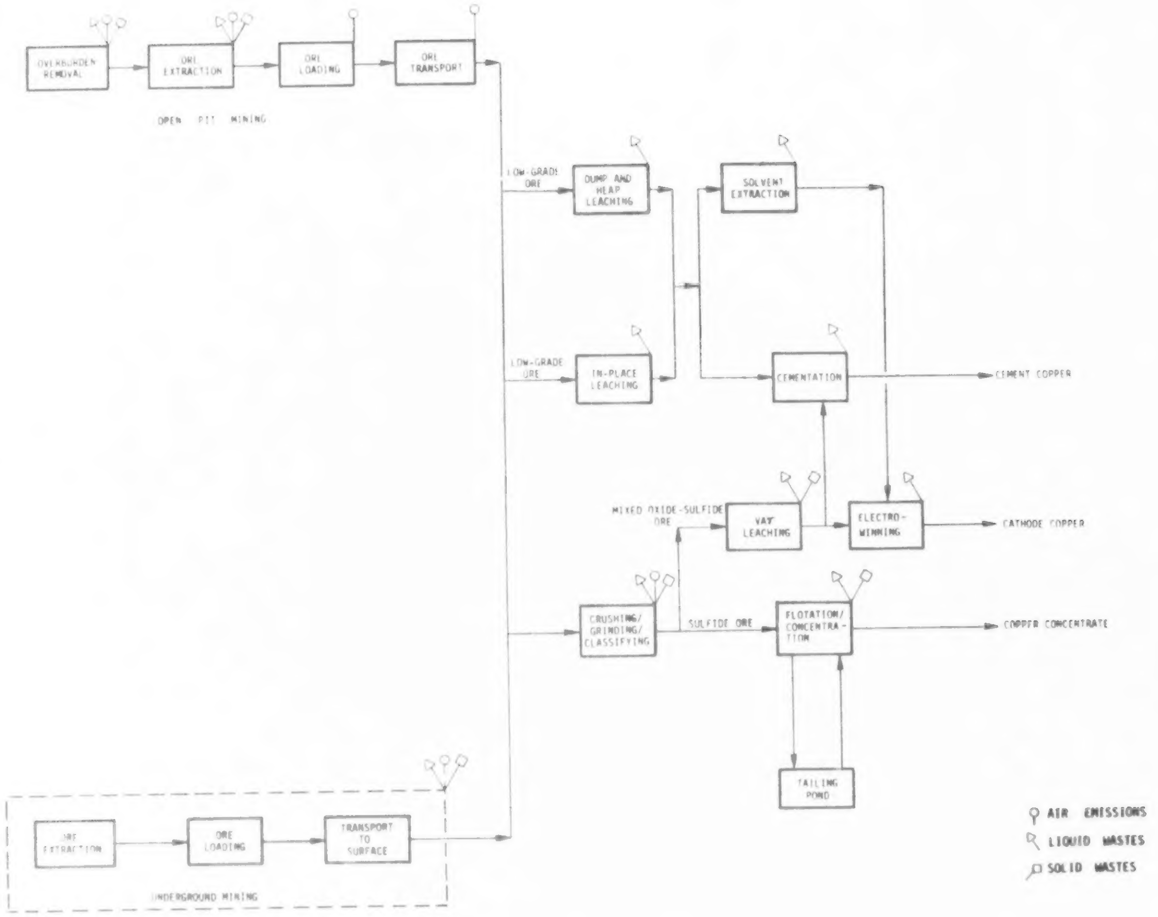
OVERBURDEN REMOVAL
ORE EXTRACTION
ORE LOADING
ORE TRANSPORT
OPEN PIT MINING
LOW-GRADE ORE
DUMP AND HEAP LEACHING
SOLVENT EXTRACTION
LOW-GRADE ORE
IN-PLACE LEACHING
CEMENTATION
CEMENT COPPER
MIXED OXIDE-SULFIDE ORE
VAT LEACHING
ELECTRO-WINNING
CATHODE COPPER
CRUSHING/ GRINDING/ CLASSIFYING
SULFIDE ORE
FLOTATION/ CONCENTRA-TION
COPPER CONCENTRATE
TAILING POND
ORE EXTRACTION
ORE LOADING
TRANSPORT TO SURFACE
UNDERGROUND MINING
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES

Figure 24. Mining and beneficiating of copper ores.

TABLE 22. CONCENTRATING ALTERNATIVES FOR COPPER ORES

Ore type	Process code	Process	Waste material	Potentially hazardous waste
Sulfide-pyrite	A	Flotation	Yes	Yes
Sulfide-pyrite	B	Flotation	Yes	Yes
Sulfide-pyrite	C	Dump leach	No	No
Oxide	D	Vat leach	Yes	No
Oxide	E	Heap leach	No	No
Oxide	F	In situ leach	No	No
Oxide	G	Dump leach	No	No
Both	H	Iron precipitation	Yes	No
Both	I	Electrowinning	No	No
Both	J	Solvent extraction	No	No
Oxide	K	I + J	No	No
Oxide	L	D + I	No	No
Oxide	M	E + K	No	No
Oxide	N	E + H	Yes	No
Oxide	O	G + H	Yes	No
Oxide	P	F + H	Yes	No
Oxide	Q	F + K	No	No
Sulfide-pyrite	R	C + H	No	No
Oxide	S	D + H	Yes	No

Source: Ref. 77.

secondary ball mills are in closed circuit and are equipped with classifiers so that the coarse material circulates for regrinding, whereas the fine feed material is delivered for flotation.

The finely ground pulp is then conditioned to adjust its alkalinity before it is fed to the flotation cells. Air and a small amount of frother, which might be pine oil or a long chain alcohol, are added in the flotation cells to produce a froth. Small amounts of chemicals referred to as "collectors" are also added, whereupon the copper sulfide particles attach themselves to air bubbles and rise to the top of the tank as a froth, which is skimmed off as concentrate. The gangue sinks to the bottom of the tank and is removed as a tailing. Following flotation, the concentrate is thickened, filtered, and shipped to a smelter.

Four principal hydrometallurgical methods are practiced: (1) in situ leaching; (2) dump leaching; (3) heap leaching; and (4) vat leaching (69). In all four methods the copper-containing solids are leached with a dilute solution of sulfuric acid or acidic ferric sulfate.

In-place leaching techniques are applicable to shattered, broken, or porous ore bodies in place on the surface or in old underground workings. Usually, abandoned underground ore bodies previously mined by block-caving methods are leached. In underground workings, leach solution is applied by sprays or other means to the lower levels, from which the solution is pumped to the precipitation plant at the surface. The leaching of surface ore bodies is similar to a heap or dump leach, except permeability sometimes must be created by blasting the ore body prior to leaching.

Most leach dumps are deposited upon the surrounding topography. Dump sites are selected to assure impermeable surfaces and to utilize the natural slope of ridges and valleys for the recovery and collection of pregnant liquors. The leach solution is recycled from the precipitation or other recovery operation, along with makeup water and sulfuric acid additions, and is pumped to the top of dumps, where it is delivered by sprays, flooding, or vertical pipes.

Heap leaching of waste dumps that are near ore grade usually is conducted on specially prepared surfaces. Copper is dissolved from porous oxide ore. The difference between heap and dump leaching is insignificant.

Vat leaching techniques require crushing and grinding of high-grade oxide ore. Dry or slurried crushed ore is placed in lead-lined tanks, where it is leached with sulfuric acid. This method is applied to nonporous oxide ores for better recovery of copper in shorter time periods. The pregnant copper solution drawn off the tanks contains very high concentrations of copper as well as some other metals. The copper is recovered by iron precipitation or by electrowinning.

The acid solution from in-place dump and heap leaching is piped to a cementation process, which converts soluble copper into a metallic precipitate through a chemical reaction with scrap iron. The resulting product, called cement copper, is sent to a smelter for processing.

Waste Streams

Table 23 presents a summary of multimedia wastes from the mining and beneficiation of copper ores. The following paragraphs offer more details regarding the various atmospheric emissions, liquid wastes, and solid wastes.

Air Emissions--

Open-pit copper mining operations generate fairly large amounts of fugitive dust. An estimate of 0.11 kilogram of fugitive dust per megagram of ore mined is presented as the overall average for several nonferrous mining operations (80).

Overburden removal, blasting, and loading and transporting operations contribute to fugitive dust emissions. The following are the primary sources associated with overburden removal:

- Dumping of dragline buckets or shovels filled with overburden material into adjacent trenches or spoil banks.
- Operation of scrapers and bulldozers in topsoil and subsoil removal and transfer.

The estimated emission factor for overburden removal at open-pit copper mines (based on a single mine near Butte, Montana) is 0.40 gram per megagram of ore mined (79). Even though blasting and drilling are periodic operations of short duration, they also generate large amounts of fugitive dust at open-pit copper mines. It is estimated that daily blasting at a large open-pit copper mine emits about 90.7 kilograms of suspended material per blast, or about 0.50 gram per megagram of ore (65). This estimate is based on visual observation and is considered to be only an order-of-magnitude value. Truck loading, another major source of fugitive dust at open-pit copper mines, generates dust at many points, but mainly during the scooping of loose material by shovel, dumping from the shovel bucket into the truck bed, and movement of the trucks into loading position. It is estimated that loading operations contribute dust at an average emission

TABLE 23. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF COPPER ORES

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal	Fugitive particulates	0.40 g/Mg ore[a]	Overburden removal			Overburden removal	Soils and native rock	0.12 Mg/Mg ore[e]
Blasting and drilling	Fugitive particulates	0.50 g/Mg ore[a]	Ore extraction	See Table 25	See Table 25	Ore extraction	Waste rock	0.95 Mg/Mg ore[f]
Ore loading	Fugitive particulates	0.025 kg/Mg ore[a]	Underground mining					
Haul roads	Fugitive particulates	0.50 and 0.18 kg/annual vehicle mile[b]	Crushing/ grinding/ classifying	N.A.	N.A.			
Underground mining	Fugitive particulates	N.A.						
Crushing/ grinding/ classifying	Particulates	1 kg/Mg ore[c]	Flotation/ concentration	See Table 27	See Table 27	Flotation/ concentration	Concentrator tailings	2.0 Mg/Mg ore[f]
Dried tailings	Fugitive particulates	9-35.8 Mg/hectare/yr[d]	Leaching	N.A.	N.A.	Vat leaching	Tailings	N.A.
			Solvent extraction	Heavy metals	N.A.			

[a] Ref. 81.

[b] Ref. 81. These values represent emissions from haul trucks and pickup trucks, respectively.

[c] Ref. 33.

[d] Ref. 65. These values were calculated using the wind erosion equation.

[e] Ref. 78. These are average quantities for 1973.

[f] Ref. 77. Average based on total national solid wastes generated in 1974.

N.A. - Not available.

rate of 0.025 kilogram per megagram of ore (65). Haul roads (usually temporary unpaved roads between active mining areas), tipple, waste disposal areas, and equipment service areas are additional sources of fugitive dust. Fugitive emissions emanating from haul roads vary with vehicle type, vehicle speed, and moisture content of the road surface. Emission factors for haul trucks and pickups are estimated at 0.5 and 0.18 kilogram per annual vehicle mile traveled (65).

The major sources of fugitive dust associated with the beneficiation of copper ores are crushing, grinding, and classifying. Dust quantity emanating from these sources is reported to be about 1 kilogram per megagram of ore (81).

Wind erosion of tailings piles results in large amounts of suspended particulates at some copper mining operations. Although no data are available on emissions from tailings piles, estimates can be obtained by applying calculations from the wind erosion equation that has been used to predict emissions from tailings piles in previous publications. This is assumed to be a valid approach as tailings pile emissions are caused by wind erosion across flat, exposed surfaces (33). Table 24 presents emission factors in megagrams per hectare per year for a wide range of "C" factors and climatic conditions.

TABLE 24. EMISSION FACTORS FOR TAILINGS PILES

Climatic factor, (C)[a]	Emissions, Mg/hm$_2$/yr
30	9.0
40	11.9
50	14.8
60	17.9
70	21.3
80	23.5
90	27.3
100	29.8
120	35.8

[a] $C = 0.345 \dfrac{W^3}{(PE)^2}$

where: W = mean annual wind velocity, in mph, corrected to a standard height of 30 feet

PE = Thornthwaite's precipitation - evaporation index = 0.83 (sum of 12 monthly ratios of precipitation to actual evaporation).

Source: Ref. 33.

The following characteristics were considered in calculating the values presented in Table 24: sandy and loamy sand soils with possible fines for surface cementation; a smooth unridged surface; no vegetative cover; an unsheltered length of 610 meters; and a climatic factor dependent on the geographic location of the tailings pile.

Liquid Wastes--

Wastewater from copper mines originates from seepage or runoff from the mine and from utility water sent into the mine. The amount of wastewater from open-pit mines ranges from zero to 0.3 cubic meter of water per megagram of ore mined, and the amount from underground mines ranges from 0.008 to 4.0 cubic meters per megagram of ore (29).

The primary chemical characteristics of mine waters are a pH varying from 2.0 to 9.5, a high dissolved solids content, the presence of oil and grease, and the presence of dissolved metals. Mine water often has a high sulfate content, and acid mine water can cause the dissolution of metals such as aluminum, cadmium, copper, iron, nickel, zinc, and cobalt (29). Table 25 presents an analysis of waters from two copper mines.

The quantity and characteristics of effluent from grinding operations have not been reported.

The flotation/concentration process contributes the greatest volume of wastewater (29). Ore flotation water is used to sluice the tailings into a pond. Although part of this water is recycled to the plant, the rest is discharged. Excluding the amount lost by evaporation and seepage in the tailings pond, the volume of wastewater emitted by this process equals the water consumption and ranges from 100 to 500 cubic meters per megagram of concentrate (81). Reported analyses indicate that wastewaters from flotation operations usually contain high levels of suspended solids and a variety of dissolved solids. The various dissolved materials present are a function of the characteristics of the ore being processed and the types of reagents added during processing. Table 26 gives examples of chemical agents that are used in copper flotation. Some of the elements that may be present in flotation wastewaters, are potentially hazardous (cadmium, copper, lead, and zinc). Table 27 represents an analysis of tailings discharged from a copper concentrator, and Table 28 presents analytical data on tailings in the impoundments of 15 different domestic mining operations.

Water usage in the vat leaching process at three mills is reported to range from 52 to 206 cubic meters per megagram of product (29). Since the leach solution from this process is sent for further processing by electrowinning or cementation, no waste

TABLE 25. RAW WASTE LOAD IN WATER PUMPED FROM SELECTED COPPER MINES[a]

Parameter	Underground mine		Open-pit mine	
	Concentration, mg/ℓ	Raw waste load per unit ore mined, kg/Mg	Concentration, mg/ℓ	Raw waste load per unit ore mined, kg/Mg
Flow	3,815.3m^3/day	0.017 m^3/Mg	409 m^3/day	0.075 m^3/Mg
pH	7.37[b]	7.37[b]	6.96[b]	6.96[b]
TDS	29,250	5.05	1,350	0.101
TSS	69	0.012	2	0.0002
Oil & grease	<1.0	<0.00017	7	0.0005
TOC	<4.5	<0.00078	10	0.00075
COD	819	0.142	4	0.0003
B	2.19	0.00038	0.07	0.000005
Cu	0.87	0.00015	1.05	0.00008
Co	<0.04	<0.000007	<0.06	<0.000005
Se	<0.077	<0.000013	0.096	0.000007
Te	0.60	<0.00010	<0.2	<0.00002
As	<0.07	<0.00001	<0.01	<0.0000008
Zn	2.8	0.00048	0.1	0.000008
Sb	<0.5	<0.000086	<0.5	<0.00004
Fe	<0.1	<0.000017	<0.1	<0.000008
Mn	2.22	0.00038	0.9	0.00007
Cd	<0.02	<0.000003	<0.03	<0.000002
Ni	<0.05	<0.000009	<0.05	<0.000004
Mo	<0.5	<0.000086	<0.2	<0.00002
Sr	119	0.0206	0.8	0.00006
Hg	<0.0001	<0.00000002	<0.0001	<0.000000008
Pb	<0.1	<0.000017	<0.5	<0.00004

[a] Source: Ref. 29.

[b] Value of pH units.

TABLE 26. EXAMPLES OF CHEMICAL AGENTS THAT ARE EMPLOYED IN COPPER FLOTATION

Mineral	Precipitation agent	pH regulation	Dispersant	Depressant	Activator	Collector	Frother
Bornite	-	Lime	Sodium silicate	Sodium cyanide	-	Xanthate, aerofloats	Pine oil
Chalcocite	-	Lime	Sodium silicate	Sodium cyanide	-	Xanthate, aerofloats	Pine oil
Chalcopyrite	-	Lime	Sodium silicate	Sodium cyanide	-	Xanthate, aerofloats	Pine oil
Native copper	-	Lime	Sodium silicate	Sodium cyanide	-	Xanthate, aerofloats	Pine oil
Azurite	Sodium monosulfide	Sodium carbonate	Sodium silicate	Quebracho	Polysulfide	Xanthate, areofloats, fatty acids	Pine oil, vapor oil, cresylic acid
Cuprite	Sodium monosulfide	Sodium carbonate	Sodium silicate	Quebracho	Polysulfide	Fatty acids and salts, xanthates	Pine oil, vapor oil, cresylic acid
Malachite	Sodium monosulfide	Sodium carbonate	Sodium silicate	Tannic acid	Polysulfide	Fatty acids and salts, xanthates	Pine oil, vapor oil, cresylic acid

Source: Ref. 29.

TABLE 27. ANALYSIS OF TAILINGS DISCHARGED FROM A COPPER CONCENTRATOR

Element	Concentration, ppm	
	Concentrator	Background
Cadmium	1172	1500
Cadmium	1.4	
Copper	2179	21
Iron	264,667	11,800
Potassium	115	1800
Magnesium	6051	3700
Manganese	19,129	490
Sodium	75	151
Lead	1349	51
Antimony	462	
Zinc	868	150

Source: Ref. 13.

TABLE 28. ANALYTICAL DATA ON TAILINGS SOLID FOR 15 COPPER MINING OPERATIONS

	Concentration, ppm unless indicated														
Copper	750	700	2600	930	1900	2000	500	1000	2100	1500	1300	1850	1300	1800	2500
Molybdenum	0.47														
Sulfur	8000														
Iron	29,000														
Gold (oz/ton)	0.005														
Silver (oz/ton)	0.02														
Rhenium (oz/ton)	0.004														
Aluminum	7000														
Arsenic	-	Nil									5				
Cadmium	5000												60		
Lead		200									7		100		
Magnesium	12,000														
Phosphorus	10,000														
Potassium	50,000														
Silicon	32,000														
Sodium	20,000														
Titanium	10,000														
Zinc	-	2300									30		30	1500	2000
Zirconium	5000														
Cyanides		Nil													
Mercury															
Selenium											0.01				
Chromium											1		290		

Source: Ref. 77.

is discharged directly. The only waste occurs from possible leakage in spent leach solution.

The barren leach solution from in-place, dump, and heap leaching is always recycled. Buildup of iron salts in leach solutions causes the worst problem in leaching operations. The pH must be maintained below 2.4 to prevent the formation of iron salts, which can precipitate in pipelines, on the dump surface, or within the dump, and cause uneven distribution of solution. Iron salts may also be removed by use of bleed streams or settling or holding ponds, where the iron salts may precipitate before recycling. Other metals such as cadmium, nickel, cobalt, manganese, and zinc are often found in high concentrations in leach solutions. Total and dissolved solids often build up to the extent that a bleed cannot be avoided. A small amount of solution containing dissolved solids may be sent to a holding or evaporation pond for control purposes (29).

No liquid wastes can be directly attributed to the cementation process, except possibly from spills. Stripped solutions are ponded for recycling.

A small amount of liquid waste may be discharged in connection with cleaning of the completed cathodes from the electrowinning process. However, no reports of this source have been published.

The solvent extraction process is likely to produce a bleed of the concentrated acid to prevent accumulation of some heavy metals contained in the solvent.

Solid Wastes--

Large volumes of solid waste are produced annually by the mining and beneficiating of copper ores. The major sources are overburden, waste rock, and concentrator tailings. The amount generated from these sources varies from mine to mine and depends on three factors: whether the mine is underground or open-pit; the ore grade; and whether ore is oxide, sulfide, or mixed oxide-sulfide (77). Usually, less solid waste is generated at underground mines than at surface mines because no overburden is removed at underground mines and the generally higher grade of the ore results in the production of less waste rock and less concentrator waste. Ore type determines the method of concentrating, and the method determines the amount of concentrator waste generated. Concentration by flotation, for example, generates more solid wastes than concentration by leaching or precipitation.

In 1974, a total of 383 million megagrams of copper ore was produced. The total amount of solid waste generated that year, including all major sources (overburden, waste rock, and concentrator tailings), was 1423 million megagrams (77). This represents a ratio of 3.7 to 1. The breakdown of total solid waste produced in 1974 is 44.5 million megagrams of overburden (0.12 megagram of waste per megagram of ore); 365.7 megagrams of waste rock (0.95 megagram of waste per megagram of ore); and 772.4 megagrams of concentrator tailings (2.0 megagrams of waste per megagram of ore) (77). These data indicate that concentrator tailings represent the largest source, approximately 54 percent of the total.

Overburden and waste rock contain small and varying amounts of copper minerals, occasionally small amounts of minerals of other metals, and large amounts of native rock. Concentrator tailings are composed primarily of the common rock-forming minerals, but they also contain approximately 15 percent of the heavy metals originally found in the ore and much of the pyrite. The tailings also contain the various reagents added throughout the concentration operation. Since the minerals in concentrator solid waste have been pulverized and intimately mixed, they are subject to weathering much more rapidly than natural rock masses of similar composition. The soil that they form is usually highly acidic, has no plant nutrients, and is phytotoxic (78). It is believed that overburden waste and waste rock contain no potentially hazardous materials. On the other hand, 65 percent of concentrator waste, is estimated to be composed of hazardous materials. Approximately 461 million megagrams of the 772 million megagrams of concentrator waste generated in 1974 is believed to have been potentially hazardous material (77).

Vat leaching produces a large amount of tailings that is sluiced into a tailings pond. This material is comparable to the waste from a concentrator plant. Frequently the same pond is used for both concentrator and vat-leached tailings (78).

None of the other leaching operations produce any solid wastes as such because solids are carried either as suspended particles or as dissolved solids in solution.

Control Technology

Typical control technologies as applied to the mining and beneficiation of copper ores are described in the following paragraphs.

Air Emissions Control--

Particulate emissions at copper mines are generated by a variety of individual operations (blasting, hauling, loading, etc.). Nearly all of the facilities that control emissions apply one or a combination of three basic techniques: watering, chemical stabilization, and reduction of surface wind speed across exposed surfaces (65).

Watering generally requires the least initial cost, but it also provides the most temporary dust control. Depending on its source, dust can be suppressed effectively by watering for only a few hours or for several days. Therefore, the frequent watering required to reform the moisture film can become costly. Also, dust control by watering is usually less than 50 percent efficient.

It should also be pointed out that fugitive dust problems related to copper mining are most prevalent in regions with arid climates and the resulting lack of natural surface moisture. As a corollary to this, water is scarce and therefore not readily available for dust control. Watering is practiced primarily to control dust emissions from haul roads. The water is usually applied by large tank trucks equipped with a pump and directional nozzles that spray the road surface and adjacent shoulders and berms. Fixed pipeline spray systems are sometimes used on relatively permanent main haul roads. Some facilities pave haul roads to control fugitive dust. Such roads are frequently swept and watered to minimize emissions. Although watering is also used to control dust emissions from overburden removal, storage, and waste disposal operations, it is rarely the only technique applied to suppress dust from these sources. The vast area and quantities of material to be covered and logistics and related costs of supplying the necessary volumes of water to the remote areas where these operations are usually located preclude its singular use.

The application of chemical stabilizers is more effective than watering in reducing fugitive dust, usually resulting in a control efficiency of 90 percent. Different properties in the chemicals promote dust suppression. They are generally categorized by their composition -- bituminous, polymer, resin, enzymatic, emulsion, surface-active agent, ligninsulfonate, latex, etc. The wide range of characteristics available in commercial products, make it possible to select a chemical stabilizer with maximum efficiency for each specific dust control application. Chemical stabilizers are used to a limited extent to control dust from mining haul roads, storage piles, and inactive tailings piles. The chemical stabilizers can be added to water or applied independently to improve binding and reduce dusting. The chemicals can be applied to the surface of the source being treated or be worked into the soil to a depth of 5 to 15 centimeters (65). Stabilizers are usually applied by truck or piping spray systems, but they can also be applied by plane. A Kennecott Copper mine west of Salt Lake City successfully stabilized 405 hectares of inactive tailings by aerial application of chemicals (65).

When treating storage piles with stabilizers, the chemicals are usually added in water spray systems. Some chemicals remain effective without reapplication for weeks, sometimes months.

As explained in the air emissions section, wind contributes significantly to all fugitive dust sources in the mining industry, by erosion of exposed surfaces of storage areas, tailings piles, and reclaimed areas and by direct transport of the dust generated by the other mining operations. Therefore, reduction of surface wind speed across the source is a logical means of reducing emissions. This speed reduction is achieved by windbreaks, enclosures or coverings for the sources, and planting of tall grasses or grains on or adjacent to exposed surfaces. Vegetative techniques require soil that supports growth, meaning they must contain nutrients, moisture, and proper texture, and be free of phytotoxicants. These requirements, especially adequate moisture, are often difficult to meet in many copper mining areas, making natural protection against wind erosion insufficient.

The large size of most fugitive dust sources in the mining industry precludes the widespread use of enclosures or wind barriers as practical solutions (65). Exceptions include the use of mats for safety purposes during minor blasting operations at some sites; the construction of some silos and other enclosed facilities for storage of relatively small quantities of mined material; the enclosure of conveying systems, with hooding connected to control devices such as scrubbers or baghouses; and the application of hooding to control the fugitive dust from truck dumping and crushing. The depressed location of overburden removal and shovel/truck loading operations usually creates a natural wind barrier for these sources.

Dust generated by the beneficiation of copper ores, particularly that resulting from crushing and grinding operations, is generally reduced by drawing air through the equipment and collecting the dust with cyclone separators. This is both a means of dust control and an integral part of the process, since it allows these small particles to bypass one or more crushing and grinding operations. Fugitive dust usually is uncontrolled, unless the amount being lost provides economic justification for recovery equipment.

Liquid Waste Control--

Mine water generated from natural drainage is reused in mining, leaching, and milling operations whenever possible. Some large mines in arid regions produce no discharge because of natural evaporation and percolation into the ground.

Those mines that produce excess wastewater can recycle it as makeup water in dump, heap, or in-place leaching. As a leach solution, this effluent is acidified, percolated through the waste dump, sent through an iron-precipitation facility, and recycled to the dump.

At many facilities mine-water effluent also is used as mill process makeup water. The mine water may pass through the process first, or it may be conveyed to the tailing pond for use in mill flotation with recycled process water.

Acid mine water that occurs in the copper mining industry is usually neutralized by the addition of lime and limestone. Acid mine water containing dissolved metals may be treated effectively by combining the mine water with the mill tails in the tailings pond. The wastewater may be further treated by lime clarification and aeration. Lime precipitation is often used to facilitate the removal of heavy metals from wastewater by precipitation as hydroxides. Application of this treatment technology yields reductions approaching 100 percent of several heavy metals (29).

Process water from froth flotation is normally directed to a large lagoon to settle out suspended solids. Effluent from the lagoon is recycled to the flotation cell or to other facilities as makeup water.

Effluent from vat leaching usually is completely recycled. Similarly, the acid solutions from dump, heap, and in situ leaching are usually completely recycled. At some mines the effluent is recirculated through a tailings pond.

No special controls for effluent from solvent extraction are indicated. The possible acid blowdown should be of a quality that could be reused in leaching processes. Also, no special controls are applicable to wastewater from the cementation and electrowinning process.

Solid Waste Controls--

Tailings from the concentration process are discarded in a tailings pond. Upstream construction of the tailings pond is more common but downstream construction occurs occasionally. As the ponds become full of solids, they are either abandoned or the tailings are dredged or mechanically moved to form an embankment and the pond raised via a peripheral discharge system. Tailings from vat leaching also are discarded in the tailings pond. Low sulfide tailings are sent to a dump for storage for possible exploitation by future technologies.

Aside from site selection and stability control little reclamation of solid wastes is practiced by the copper mining and beneficiating industry. Only a few companies control blowing dust or attempt to reclaim or naturalize the dump areas. When stabilization and revegetation practices are attempted, a variety of problems can develop, particularly if excessive salinity or acidity are encountered. Sometimes lime and sewage sludge are applied to ameliorate acidity. In areas where water is available, soluble salts can be leached downwards by excessive irrigation prior to revegetating. Leaching, however, may complicate the situation because the tailings may contain both salts and pyrite. In arid climates, the pyrite is likely to be inactive and have a high initial pH (43). The tailings generated by the Utah Copper Division mill of the Kennecott Company has these characteristics, and they are discarded in a semiarid environment. This material has a pH of 7.8 when fresh, a salinity equivalent to 2.4 atmospheres osmotic concentration, and pyrite content of approximately 1.3 percent (43). The salts in the tailings produce an osmotic gradient that transfers fluid from the plants. Thus, vegetation dies of dehydration as irrigation of the plants leaches away the salts, the pyrite oxidizes, and the pH may drop from 7.8 to less than 3.0 within a month's time.

Conclusions and Recommendations

Fugitive dust generated by such sources as haul roads, ore loading and dumping, and overburden removal, is a major pollution problem at many copper mining operations. Dust control provided by watering of haul roads and actively worked areas is of such a temporary nature that chemical stabilizers furnish a more cost-effective dust suppressant. More than 100 proprietary chemical stabilizers are available, all reputed to be effective for controlling dust on unpaved traffic areas. Some comparative studies of these different stabilization chemicals would be valuable.

A major area of concern associated with copper mining and beneficiation operations is the disposal of tailings. Mining and milling operations generate large volumes of tailings annually, and many of these wastes contain potentially hazardous materials such as heavy metals. Most tailings are discarded into tailings ponds, but because most of the ponds are not lined, the heavy metals may leach into and cause contamination of the groundwater. Therefore techniques for the removal of the heavy metals should be evaluated and/or sealing ponds should be investigated. Sealing existing ponds constitutes a major technolgical hurdle.

Another area for possible research is the development of mechanical screening and filtering equipment to separate tailings from concentrator water. Tailings are commonly removed from flotation water by allowing them to settle in a pond. This solid waste could be controlled more effectively if a mechanical device that continuously separates tails from water could be developed to operate economically. The chance of developing an economic alternative are remote at present.

The development of a reagent that can replace sodium cyanide as a flotation depressant would constitute a contribution to pollution control technology. Cyanide that enters a copper mill tailings pond is stable in solution because the pond water pH is above 9 (often as high as 10). Therefore the cyanide escapes with any seepage that occurs. The development of an alternative reagent would eliminate the risk associated with this pollutant.

Many projects are currently in progress to reclaim inactive tailings by covering the surfaces with suitable soils and revegetating them. Other copper tailings have been stabilized chemically by encouraging encroachment of natural vegetation, or stabilized physically by covering with smelter slag, gravel, wood bark, or straw. Many times, however, pH and associated parameters of copper tailings are such that they present detrimental obstacles to revegetation and stabilization. Research and development of mechanisms for overcoming this problem would be beneficial.

GOLD

Industry Description

Gold is found in the earth's crust in extremely low concentrations, perhaps 5×20^{-9} gram per gram in igneous rocks, 0.25×10^{-6} gram per gram in the earth as a whole. It is also found in seawater, which is estimated to contain about 4×10^{-12} gram per gram (46). Local concentrations of gold, sufficiently high to mine economically, are produced by various geochemical processes associated with quartz, sulfides, and tellurides. Natural eroding of gold-bearing rocks combined with the current of flowing streams often results in substantial local concentrations of gold in placers (82). Some gold also is recovered during electrolytic refining of copper, nickel, and other metals. Fifty to 60 percent of domestic gold production comes from gold ores; the rest is recovered as a coproduct of copper, zinc, or lead (14).

The gold industry is concentrated in eight states: Alaska, Montana, New Mexico, Arizona, Utah, Colorado, Nevada, and South Dakota (29). The total domestic output comes from an estimated 140 firms, and 75 percent of the 1974 total came from the four largest firms (14).

Most of the gold used in industry is in the form of metal or metal alloys. Industrial gold is shaped into bars, rods, sheets, foils, wires, powder, granules, and shot. Gold used in high-quality jewelry is measured in karats and is an alloy of gold, copper, and other metals such as silver, zinc, and platinum. For example, 14-karat gold contains 58.3 percent gold; approximately 25 to 32 percent copper; and varying small percentages of the other metals. Substantial amounts of gold also are used to electroplate jewelry and decorative articles, and as rolled gold, gold plate, and gold fill. A variety of organic gold compounds also are produced for electroless gold plating. The jewelry and aerospace industries use brazing alloys containing gold. The dental profession uses gold extensively. Alloys containing 25 to 70 percent gold are used in wire form for orthodontic applications; other alloys (with 60 to 92.5 percent gold) are used in cast form in inlays, crowns, and bridges. Gold alloys are also produced for solders. The electronics industry produces bimetallic strips in a variety of shapes and patterns, with gold applied selectively to electrical contact areas. Tiny wires for transistor connections are made of gold. Specialized gold compounds are made for diverse uses, such as in medicines and glass (14).

Process Description

Gold is mined from two types of deposits: placers and lodes or veins. About 1 percent of domestic gold comes from placer deposits (46), approximately 33 percent from underground mines, and the remainder from open-pit mines (14).

Processes for the recovery and beneficiation of gold and gold-containing ores include cyanidation, amalgamation, flotation, and gravity concentration. All of these have been used to beneficiate ore mined from lode or vein deposits. Only gravity methods (sometimes in conjunction with amalgamation) are used in placer operations, however, in the past few years, the restriction placed on the use of mercury has caused the use of amalgamation to decrease while the use of cyanidation has increased (29). Many mines use two or more processes, and the tailings from one process, such as flotation or gravity separation, are further processed by cyanidation to recover residual gold values. Figure 25 shows a flow sheet for mining and beneficiation of gold.

Placer mining consists of excavating gold-bearing gravel and sand, now primarily by dredging. (In the past, hydraulic mining and drift mining also were used.) The excavated gold-bearing deposits are dumped into a feed hopper and conveyed to a washing hommel screen. In the scrubbing section of the hommel screen, the gravels are washed thoroughly to disintegrate all clay before they are screened to reject the oversize. The undersize from the screen passes to a jig for gravity separation, then the high grade ore concentrate is discharged from the jig to a dewatering screw classifier for removal of excess water.

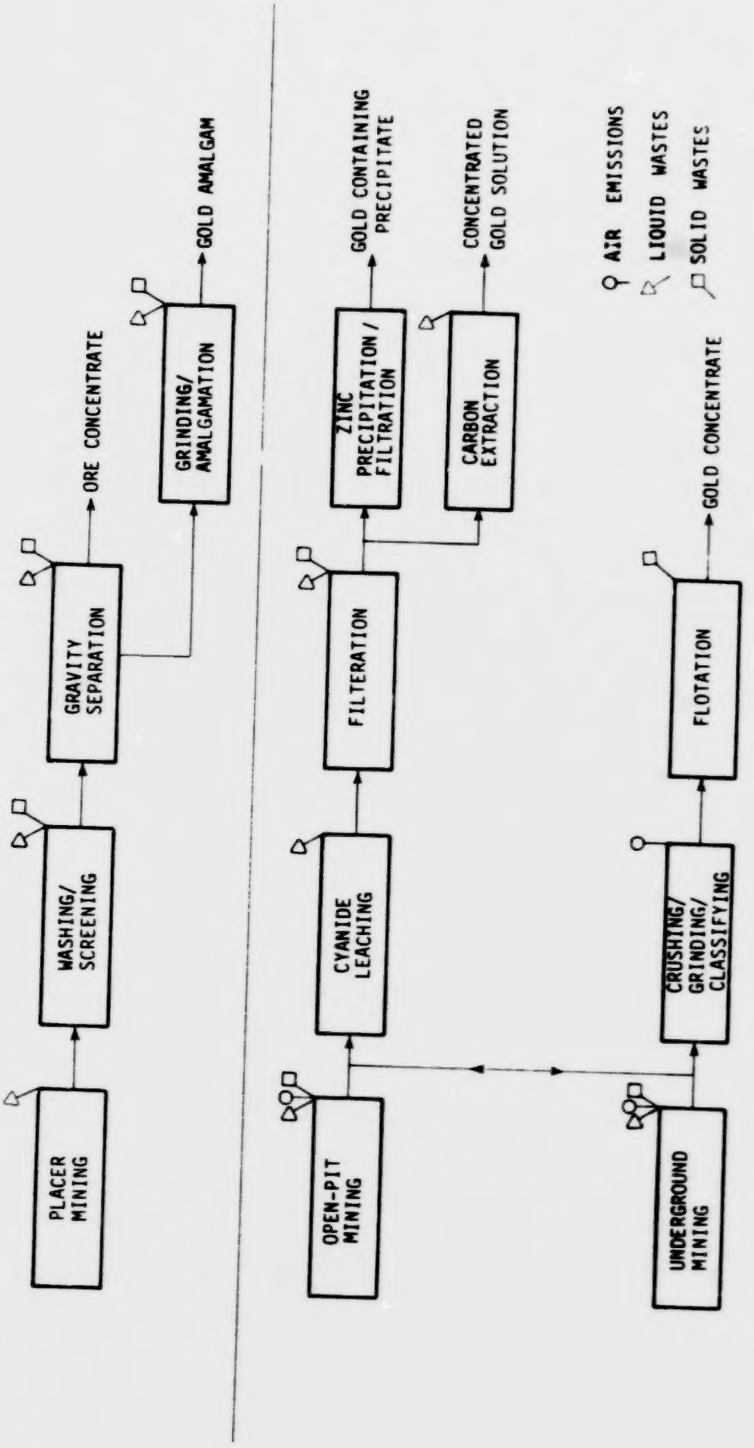
PLACER MINING
WASHING/ SCREENING
GRAVITY SEPARATION
ORE CONCENTRATE
GRINDING/ AMALGAMATION
GOLD AMALGAM
OPEN-PIT MINING
CYANIDE LEACHING
FILTERATION
ZINC PRECIPITATION/ FILTRATION
GOLD CONTAINING PRECIPITATE
CARBON EXTRACTION
CONCENTRATED GOLD SOLUTION
UNDERGROUND MINING
CRUSHING/ GRINDING/ CLASSIFYING
FLOTATION
GOLD CONCENTRATE
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES

Figure 25. Mining and beneficiating of gold ores.

Sometimes, placer mines use amalgamation to recover the lean ore left from gravity separation. This process involves first grinding the ore in a ball mill, then passing the pulp of crushed ore and water over mercury-treated (amalgamated) copper plates, to which the gold particles adhere. The amalgate of gold and mercury is scraped off from time to time. Much of the mercury is recovered and returned to the process.

Lode deposits of gold are recovered from open-pit and underground mining by the conventional mining techniques described in Section 2. The ore is transported to the mill house, where recovery and beneficiation takes place by cyanidation, flotation, or gravity separation.

Four basic methods of cyanidation currently are being used in the United States: heap leaching, vat leaching, agitation leaching, and a carbon-in-pulp process. Heap leaching is used primarily to recover gold from low-grade ore or gold mine waste dumps. Higher grade ores are crushed, ground, and vat-leached or agitated-leached to recover the gold.

Vat leaching involves filling a vat with ground ore slurry, allowing the water to drain off, and leaching the sands from the top with cyanide. This solubilizes the gold. Pregnant cyanide solution is collected from the bottom of the vat and sent to a holding tank. Agitation leaching involves adding a cyanide solution to a ground ore pulp in thickeners, and agitating the mixture until the gold becomes soluble. The cyanide solution is collected from the thickeners by decanting (29).

Impurities and suspended solids are filtered from the gold-bearing solution by passing the solution through a filtering media (coated with diatomeceous earth) in a tank (83). Zinc dust is used to precipitate the gold from the solution. The precipitate is collected in a filter press and sent to a smelter for the production of bullion.

Cyanidation of slimes generated in the course of wet grinding is currently accomplished by the carbon-in-pulp process. In large tanks the slimes are mixed with a cyanide solution and the solubilized gold cyanide is collected by adsorption to activated charcoal. Gold is stripped from the charcoal by applying a small amount of hot caustic. The concentrated gold solution is purified by electrowinning (29).

Gold that is finely disseminated in pyrites and some low grade gold ores are recovered by flotation. The ore is crushed, wet ground in a ball mill, and classified. After conditioning, the pulp flows to a flotation tank of the cell-to-cell type. Reagents for gold flotation are usually soda ash, a xanthate, and a frother. The gold-containing minerals that float to the top are collected and sent to a disk filter for dewatering. The resulting gold concentrate is further purified at a smelter.

Waste Streams

Table 29 presents a summary of multimedia wastes from the mining and beneficiation of gold-bearing ores. The following paragraphs explain in more detail the various air, liquid, and solid wastes associated with the gold industry.

Air Emissions--

Mining and beneficiation of placer-mined gold do not generate air emissions because all the processes are carried out in the presence of water.

Nothing is available on estimates and characteristics of emissions from open-pit and underground gold mines or from the crushing and grinding processes.

Liquid Wastes--

Placer mining and beneficiation processes uses large quantities of water. Although no specific data are available on the characteristics and concentrations of the effluent from washing, screening, and gravity separation, the effluent is known to have high suspended solids content and could be potentially hazardous (46).

Effluent from grinding and amalgamation is also high in suspended solids. Mercury is the prominent reagent used in this process; therefore the effluent could be potentially toxic.

In open-pit mining, the only sources of possible discharge are precipitation, runoff, and groundwater infiltration into the pit. In underground mining, groundwater infiltration is the primary source of water. Table 30 shows the chemical composition of raw mine water from two underground gold mines.

As shown in Table 30, cyanide leaching results in high levels of soluble metals. Cyanide and heavy metals are potentially toxic and are of primary concern.

No specific data are available on the environmental impacts associated with filtration operations. Neither zinc precipitation nor carbon extraction would generate much effluent because of the extreme care that must be taken to minimize gold losses.

Solid Wastes--

No information has been reported on solid wastes generated by placer mines.

TABLE 29. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF GOLD ORES

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Open-pit mining	Fugitive particulates	N.A.	Washing/ screening	SS	High[a]	Placer mining	Gangue	N.A.
Underground mining	Fugitive particulates, gases	N.A.	Gravity separation			Washing/ screening	Tailings	N.A.
Crushing/ grinding/ classifying	Particulates	N.A.	Grinding/ amalgamation	TSS	2,871 kg/Mg of ore[b]	Gravity separation	Tailings	N.A.
				TDS	0.930 kg/Mg of ore			
				TOC	0.199 kg/Mg of ore			
				COD	0.066 kg/Mg of ore	Grinding/ amalgamation	Tailings	N.A.
				Cu	0.0002 kg/Mg of ore			
				As	<0.0004 kg/Mg of ore			
				Fe	0.0087 kg/Mg of ore	Open-pit mining	Gangue	N.A.
				Zn	0.0075 kg/Mg of ore			
				Pb	<0.0006 kg/Mg of ore			
				Cd	<0.0001 kg/Mg of ore	Underground	Gangue	N.A.
				Hg	<0.0000064 kg/Mg of ore			
				Cn	<0.00006 kg/Mg of ore			
				S	<0.0029 kg/Mg of ore			

(Continued)

TABLE 20. (continued)

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
			Open-pit mining		N.A.	Filtration	Residue	N.A.
			Underground mining	c	c	Carbon extraction	Carbon particles	N.A.
			Cyanide leaching	pH	12.26[a]			
				TSS	545,000 mg/ℓ[a]			
				Turbidity	6.75 J.T.U.[a]			
				TDS	4,536 mg/ℓ[a]			
				COD	43 mg/ℓ[a]			
				Oil and grease	<1 mg/ℓ[a]			
				Cn	5.06 mg/ℓ[a]			
				As	0.05 mg/ℓ[a]			
				Cd	0.10 mg/ℓ[a]			
				Cr	0.06 mg/ℓ[a]			
				Cu	0.17 mg/ℓ[a]			
				Total Fe	<0.5 mg/ℓ[a]			
				Pb	<0.1 mg/ℓ[a]			
				Total Mn	0.02 mg/ℓ[a]			
				Zn	3.1 mg/ℓ[a]			
			Filtration	N.A.	N.A.			
			Flotation	N.A.	N.A.			

[a] Ref. 46.

[b] Ref. 67.

[c] See Table 30.

N.A. - Not available.

TABLE 30. CHEMICAL COMPOSITION OF RAW MINE WATER FROM TWO UNDERGROUND GOLD MINES

Parameter	Concentration, mg/ℓ		Parameter	Concentration, mg/ℓ	
	Mine 1	Mine 2		Mine 1	Mine 2
pH[a]	-	6.14	Mg	80.0	-
Alkalinity	275	-	Mn	0.14	11.93
Color	34[b]	-	Hg	<0.0001	-
Turbidity (JTU)	2.40	-	Ni	0.10	0.06
TOS	1,190	535	Ti	<0.05	-
TDS	1,176	530	V	<0.2	-
TSS	14	5	K	44.0	-
Hardness	733	-	Ag	<0.02	-
COD	35.01	27	Na	80.0	-
TOC	12.0	-	Sr	0.78	-
Oil and grease	1	<0.1	Te	0.10	-
MBAS surfactants	0.095	-	Ti	<0.5	-
Al	<0.2	0.143	Zn	<0.01	-
As	0.03	0.084	Sb	<1	-
Be	<0.002	-	Mo	<0.2	-
Ba	<0.5	-	Sulfate	618.75	1,192
B	0.18	-	Nitrate	5.05	-
Cd	<0.02	0.025	Phosphate	<0.05	-
Ca	87.0	-	Cyanide	<0.01	<0.01
Cr	<0.02	-	Phenol	<0.01	-
Cu	<0.02	0.056	Chloride	1.8	3
Total Fe	1.2	25.11	Fluoride	2.05	-
Pb	<0.1	0.82	-	-	-

[a] Value in pH units.

[b] Value in cobalt units.

TOS = Total solids.

Source: Ref. 29.

Open-pit mines generate considerably more waste material than underground mines, but the characteristics of these wastes are not known.

The filtration process generates residue that could be potentially hazardous if cyanide or other noxious materials are present. No information is available on the wastes generated by carbon extraction.

Control Technology

The following paragraphs explain air, liquid, and solid wastes control methods.

Air Emissions Control--

Dust from open-pit mining is minimized by water spraying. Particulates generated by underground mining usually do not require control because they are generally large and precipitate in the vicinity of the mining activity. If crushing and grinding are wet operations, they do not create a dust problem; however, dry crushing and grinding operations require control by cyclones or fabric filters.

Liquid Wastes Control--

Wastewater from placer mining operations (washing, screening, and gravity separation) is discharged into a tailings pond, where suspended solids are allowed to settle out.

Mill water from grinding and amalgamation are also discharged to a tailings pond. Decant from this pond may be discharged into a stream, or may flow into a smaller polishing pond prior to discharge into a stream. Data from one mill indicate that, the use of two settling ponds (tailings and polishing ponds) removes some additional selected metals, and achieves 99.9 percent total suspended solids removal.

One open-pit gold mine in Nevada has no discharge because of the arid climate (76). Wastewater from underground gold mines is either ponded or used as a source of process water in the mills.

Typically effluent from cyanide leaching operations is discharged to a tailings pond to oxidize the cyanide and to contain the heavy metals. In arid locations, the tailings pond decant is recycled, and no discharge to a watercourse occurs.

Tailings from the flotation process of one beneficiating facility are further processed by cyanidation/agitation, a leach process to recover residual gold values (29).

Solid Waste Control--

Most of the solid wastes generated by the beneficiation of gold is discharged into an on-site tailings pond. When one pond is filled up, a new one is worked. Although such ponds are built around a dam, they are not lined. Rather, they are built on a stratum of rocks, which prevents seepage into the groundwater. At some mines, the tailings are sent back to the mine.

Conclusions and Recommendations

Insufficient data are not available to make a final assessment of all the environmental impacts associated with mining and beneficiation of gold.

Air pollution from gold mining and beneficiation is controlled by conventional techniques and is not a major environmental concern at this time.

Most of the wastewater is discharged into a tailings pond, then either recycled to the mill or discharged into a watercourse. Solid waste is generally discarded into the same tailings pond.

One possible area of research activity could concentrate on the ultimate disposal or use of solids that settle out in the tailings pond. These solids could contain gold or other recoverable minerals. Another possible area of research involves the development of economical methods of controlling or eliminating wastewater that contains arsenic and cyanide.

LEAD AND ZINC

Although the lead and zinc industries each make a distinct product, they have been considered a single economic unit for many years because of the strong interrelation between the two industries. Their products are marketed through many of the same channels, using the same procedures. Since many of the ores contain recoverable quantities of both lead and zinc, the industries regularly exchange material, and several companies produce both metals, along with a variety of other coproducts/by-products (copper, gold, silver, etc.). The two industries also share similar production techniques and produce similar waste materials. Because of these interrelationships, lead and zinc are discussed together in this section.

Industry Description

Lead--

Although most domestic lead is recovered from ores mined primarily for their lead content, a sizable amount is recovered as a coproduct or by-product from complex ores containing zinc, silver, gold, and often copper. Other materials recovered in processing lead ores and concentrates include antimony, bismuth, tellurium, arsenic, cadmium and sulfur (as sulfuric acid). The economical extraction of lead at many operations depends on the combined values of the associated materials recovered from the ores.

Lead is most often found as galena (PbS_2), the primary sulfide of lead (77). These are rarely pure deposits. The lead-bearing compound is usually mixed with pyrite, sphalerite, and pyrrhotite. The deposits normally contain very little copper, gold, or silver. Oxidized lead ores also are found. They are composed primarily of anglesite and cerussite, which are weathered products of galena.

In amount used, lead ranks fourth among nonferrous metals (behind aluminum, copper, and zinc). As the world's leader in lead consumption and production, the United States accounted for 27 percent of the consumption and about 17 percent of the total mine production in 1974 (15). This country also has the largest reserves of lead, estimated to be adequate to handle all primary domestic requirements through the year 2000. Although reserves are adequate, some dependence on imports and government stockpiles to meet part of the domestic demand is likely to continue. (See Section 1 for additional information on present and projected production statistics.)

The lead mining industry currently consists of 31 mines in 15 states (15). The output of these mines ranges from less than 1 megagram to 100,000 megagrams per year. Greater than 80 percent of the domestic mine production comes from seven operations in the newly discovered Lead Belt of southeastern Missouri. Approximately 98 percent of the total mine production comes from four states: 85 percent from Missouri; 8 percent from Idaho; 5 percent from Colorado; and 1 percent from Utah (15).

At most large and medium-sized mines ore is concentrated at the mine site. At some smaller western mines it is trucked to centrally located concentrating facilities. Ore concentrates are then shipped to any one of the six smelters in the United States. Four of these are fully integrated lead mining and smelting operations.

Lead bullion, more than 99.9 percent pure, is the primary product of this industry. Antimonial lead, a less ductile product, is also produced. Whether the various by-products/coproducts (mentioned earlier) are generated depends on ore characteristics and market conditions. Lead is used primarily in storage batteries for automobiles and battery-powered vehicles, as tetraethyl or tetramethyllead, an antiknock additive in gasoline, and in construction materials (roofing, piping, caulking, etc.). It is also used in ammunition, paints, and electrical cable sheathing.

The market for many products of the lead industry is continually decreasing as the public becomes aware that lead and its compounds are cumulative poisons. Lead pigments rarely are used in paints anymore. Although tetraethyl lead for gasoline additives is still manufactured and continues to provide a major market for lead, its use is being restricted. In recent years other materials also have replaced lead as a joining material for cast iron pipe, in plumbing, and in most other construction applications. Although these traditional uses of lead are diminishing, factors such as the rapid growth in lead-acid batteries and the development of new uses have more than offset this decline and the demand for lead continues to grow.

Zinc--

Although most domestic zinc is recovered from ores mined primarily for their lead content, a sizable amount comes from ore containing zinc and varying amounts of other valuable and recoverable materials including lead, copper, cadmium, fluorspar, gallium, germanium, gold, indium, manganese, silver, sulfur, and thallium. Zinc may be recovered as the primary metal (as in the zinc ores of Tennessee, Pennsylvania, and New Jersey deposits) or as a by-product/coproduct as in the complex western ores or in the lead ores of the Missouri Lead Belt. Zinc recovery at most mining operations is dependent on the combined economic values of the by-products/coproducts present in the ore.

In its natural state zinc is usually found as the sulfide called sphalerite, which has a cubic lattice structure and is commonly referred to as zinc blende, blende, or jack. Zinc content can be as high as 67.1 percent in the pure phase. Wurtzite, a polymorph of sphalerite, has a hexagonal structure and is more stable at elevated temperatures. Almost all other zinc minerals have been formed as oxidation products of these sulfides. Most of these oxidized minerals are minor sources of zinc, although franklinite and zincite are mined for their zinc content at the New Jersey Zinc Co. mine (21).

Iron is the most common impurity or associated metal in zinc ore because of its chemical similarities and the relative ease of substitution in their respective lattices. Cadmium is the second most abundant impurity. It is always associated with zinc, and is usually present as greenockite (CdS). The commonly associated nonzinc minerals in zinc ores are calcite ($CaCO_3$), dolomite ($(Ca, Mg)CO_3$), pyrite and marcasite (FeS_2), quartz (SiO_2), chalcopyrite ($CuFeS_2$), and barite ($BaSO_4$).

Among nonferrous metals of the world zinc ranks third in annual consumption, behind copper and aluminum. A major consumer of zinc, the United States used approximately 20 percent of the total world supply in 1974 while it produced only 8 percent of the primary zinc supply (78). In 1974 approximately 28 percent of the U.S. zinc supply came from domestic mines and 45 percent was imported. Of the remainder, 4 percent came from secondary metal supplies; 16 percent from Government supplies and 7 percent from industry stocks. In recent years the trend has been toward less dependence on imported concentrates; however, since U.S. resources are not expected to cover the domestic cumulative demand through 2000, reliance on imports for a significant portion of supply is expected to continue. (See Section 1 for present and future production statistics for the zinc industry.)

In 1975, 18 states throughout the United States reported zinc mining production. The major producing states were Tennessee, 18 percent; Missouri and New York, 16 percent each; Colorado, 10 percent; Idaho, 8 percent; and New Jersey, 7 percent (77). Mining capacities of lead-zinc ore ranged from 10,000 to 10,000,000 megagrams per year. The 25 largest U.S. mines accounted for over 90 percent of the zinc ore mined and, the 5 largest of these accounted for 40 percent (77). A total of 43 zinc mines operated in 1975 (84). Several large firms in the domestic primary zinc industry are vertically integrated, with mines, concentrators, smelters, and refineries. In 1974, five integrated companies accounted for 89 percent of the slab zinc production in the United States and 77 percent of the total domestic mine output (15).

The major product of the primary zinc industry is metallic zinc; other products include zinc oxide, sulfuric acid, cadmium, and occasionally other chemicals such as zinc sulfate. Important by-product compounds resulting from the primary zinc industry include germanium, thallium, gallium, and indium. These by-products often are not considered part of the industry because they are not recovered at primary zinc smelters.

Uses for zinc products vary widely. Metallic zinc is used for galvinizing, for making pigments and zinc compounds, for alloying, and for grinding into zinc dust. Usage patterns in the United States differ from those in the rest of the world in that heavy emphasis is placed on zinc-based alloy castings, mainly for the automotive industry. The primary product of most zinc companies is slab zinc, which is produced in five grades and classified by its purity. Zinc oxide is used in rubber, emollients, ceramics, and fluorescent pigments, and in the manufacture of chemicals.

Metallic cadmium is used in the production of alloys, in corrosion-resistant plating for hardware, as a counter electrode metal for selenium rectifiers, as neutron shielding rods in nuclear reactors, in nickel-cadmium batteries, and in plastics and cadmium compounds. Cadmium metal accounts for 60 to 70 percent of consumption, and cadmium sulfide used for pigments for another 12 to 15 percent (22).

Process Description

Some mining operations recover ores containing lead but no zinc, others recover ores containing zinc but no lead, and still others recover ores containing both lead and zinc along with other by-products/coproducts. The ores from which lead and/or zinc are recovered are classified on the basis of the metal of major value in the ore: zinc ores, zinc-lead ores, lead ores, and all the other ores from which zinc and/or lead are obtained (e.g., copper-lead-zinc ores). The mineralogy of the ores determines the technology and economics of mining and processing practices.

Specific factors that affect mining and processing methods include size and interlocking of the mineral grains, association with other metallic and nonmetallic minerals, and oxidation or coating of mineral surfaces with soluble salts. Mining and processing differ slightly throughout the lead and zinc industries; however, ore extraction and concentrating methods are quite similar regardless of the ore type. The extraction and beneficiation techniques associated with lead-zinc ores are illustrated in Figure 26 and discussed in the following paragraphs.

Ores containing lead and/or zinc are almost always extracted by underground mining methods. A few zinc mines, particularly in early stages of operation, use open-pit methods that closely follow those of copper mining. Most lead ore is obtained by normal stoping methods such as block caving, room-and-pillar (with and without rock bolting), and cut-and-fill with timber supports. Most zinc ore is mined using open shrinkage, cut-and-fill, or square-set stoping methods. In most of the mines, walls and pillars usually are left behind to support the overlying rock structure, unless the width of the ore body is such that it can be left unsupported and the entire ore body extracted. The cycle of mining operations consists of drilling, blasting, and removing the broken rock. The ore cut from the deposit is hauled to the surface by rail tram, trackless shuttle cars, or conveyor belts, then is transported to ore concentrating facilities by rail car, truck, belt conveyor, or a combination thereof.

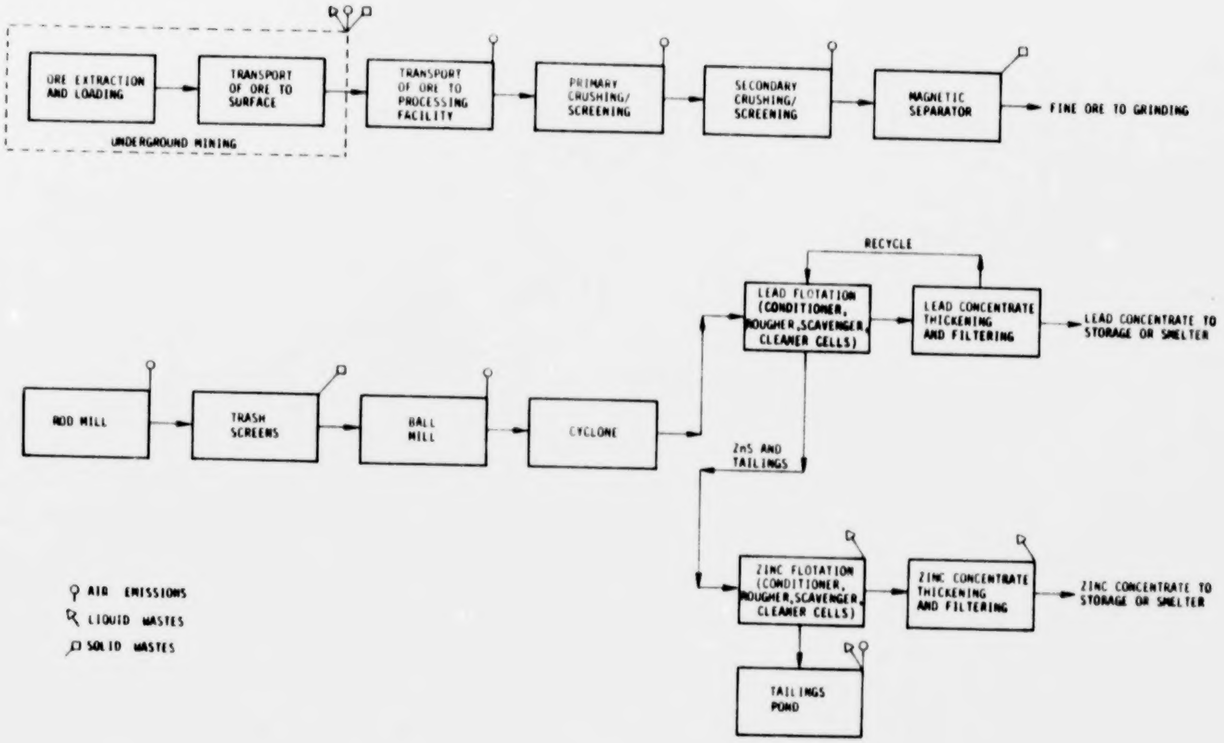
ORE EXTRACTION AND LOADING
TRANSPORT OF ORE TO SURFACE
UNDERGROUND MINING
TRANSPORT OF ORE TO PROCESSING FACILITY
PRIMARY CRUSHING/ SCREENING
SECONDARY CRUSHING/ SCREENING
MAGNETIC SEPARATOR
FINE ORE TO GRINDING
ROD MILL
TRASH SCREENS
BALL MILL
CYCLONE
RECYCLE
LEAD FLOTATION (CONDITIONER, ROUGHER, SCAVENGER, CLEANER CELLS)
LEAD CONCENTRATE THICKENING AND FILTERING
LEAD CONCENTRATE TO STORAGE OR SMELTER
ZnS AND TAILINGS
ZINC FLOTATION (CONDITIONER, ROUGHER, SCAVENGER, CLEANER CELLS)
ZINC CONCENTRATE THICKENING AND FILTERING
ZINC CONCENTRATE TO STORAGE OR SMELTER
TAILINGS POND
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES

Figure 26. Mining and beneficiating of lead-zinc ores.

Regardless of ore type and the number of recoverable materials in it, processing techniques in the industry share many similarities and almost always involve some form of crushing, grinding, concentrating, thickening, and dewatering. Lead and zinc concentrates are recovered primarily by the flotation method. Processing methods throughout the industry vary most in the type and number of flotation cells used at an operation (most facilities have two or more stages of flotation cells) and the types of flotation reagents added to the process. It should be noted that some facilities use gravity methods to preconcentrate ores that contain relatively coarse minerals easily broken free at an early stage in the crushing-grinding operations (84). These gravity methods usually consist of jigs or heavy-media (sink-float) systems placed ahead of the fine grinding part of the circuit. By removing a portion of the waste material from ores before the grinding and flotation steps, preconcentration increases the capacity of the operation and decreases the cost of flotation and grinding. The beneficiation operation illustrated in Figure 26, and discussed in more detail in the following paragraphs, applies to lead-zinc sulfide ores only. However, as stated earlier, processing practices vary little throughout the industry whether the ore type is lead, zinc, lead-zinc, or copper-lead-zinc.

The first step in the processing of lead-zinc ores involves size reduction or crushing. Primary and secondary crushing is usually accomplished by a combination of jaw and gyratory crushers with grizzly bars and screens. The ore then is conveyor-fed into fine-ore storage bins (77). Tramp iron is removed by a separator magnet operating on or under a conveyor belt between the crushing and classifying operations. The crushed ore is ground to a size that liberates the lead and zinc sulfide from the gangue, usually by wet grinding in rod and ball mills. These mills are equipped with classifiers that prepare the feed for flotation.

At most facilities, classifier overflow is passed over a vibrating screen to remove wood pulp, which is discarded. The underflow is pumped to the first cell of the flotation circuit, known as the lead conditioner cell, where a number of chemical reagents are added. These reagents include sodium ethyl xanthate, zinc sulfate, methyl isobutyl carbinol (MIBC), and sodium cyanide (85). At some operations the sodium ethyl xanthate and zinc sulfate are added earlier in the rod and ball mills to provide more contact time. Sodium ethyl xanthate is a collector, which coats the desired nonfloating mineral particles and makes them more susceptible to flotation. Zinc sulfate and sodium cyanide are depressants that inhibit the zinc sulfide particles from floating with the lead sulfide. MIBC, a frother, is added to coat and toughen the air bubbles that are introduced into the cell. The air bubbles carry the lead-laden frother to the surface of the conditioner cell, and the mixture then overflows to a second series of flotation cells, known as the lead roughers. Air bubbles are introduced at the bottom of the cell and the lead-laden frother floats to the surface, flows over weirs, and continues on to the remaining flotation cells. The underflow material, consisting of zinc sulfide and gangue, is collected at the bottom of the cell and sent to the beginning of the zinc flotation operation. The final lead flotation cells, known as scavenger and cleaner cells, further separate lead sulfide from zinc sulfide, and gangue and the residual material from the cells are recycled back to the beginning of the lead flotation circuit. The lead-laden overflow from the final flotation cells (cleaner cells) is concentrated and thickened in sedimentation tanks (86). The liquid overflow from the tanks is recycled and the lead concentrate is vacuum-filtered, dried, and stored or shipped by rail car to the smelter.

The underflow from the lead rougher cell is sent to the zinc conditioner cell and mixed with a variety of chemical additives such as Xanthate Z-11, methyl isobutyl carbinol, copper sulfate, quicklime and Separan (76). Copper sulfate activates the zinc and must be added to the slurry first to neutralize the depression action of the zinc sulfate and sodium cyanide, which were added to the lead conditioner cell. The zinc flotation circuit is identical to the lead flotation circuit in that it consists of conditioner, rougher, scavenger, and cleaner cells. Following flotation, the zinc concentrate, like the lead concentrate, is thickened, filtered, and either stored or shipped to the smelter. The tailings from the rougher flotation cells are pumped to a sand plant and passed through a cyclone. The fines from the cyclone are disposed of in a tailings pond and the coarse materials are used for mine backfill. Backfilling is not practiced at some operations and all the tailings is sent to the tailings pond.

The operations illustrated on Figure 25 and just described represent typical mining and beneficiating facilities for the recovery of lead-zinc sulfide ores. Although mining and processing operations vary somewhat throughout the industry as a function of ore type and the number of recoverable materials in the ore, such variations are small and usually involve only the type and number of flotation cells employed and the chemical reagents added to the process.

Waste Streams

Table 31 presents a summary of multimedia wastes from the mining and beneficiating of ores containing recoverable amounts of lead and/or zinc. The following paragraphs explain in more detail the various atmospheric emissions, liquid wastes, and solid wastes.

TABLE 31. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF LEAD-ZINC ORES

	Air		Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Drilling			Mine water	See Tables 32 and 33	100-200,000 m^3/day[d]	Ore extraction	Waste rock	0.0-0.24 Mg/Mg ore mined[f]
Blasting			Flotation, thickening, dewatering	Wet tailings[e]	1,000-16,000 m^3/day	Flotation, thickening, dewatering	Dry tailings	0.26-0.94 Mg/Mg ore mined[f]
Ore loading	Fugitive particulates	0.1 kg/Mg of ore mined[a]						
Ore transport								
Crushing/ grinding	Fugitive particulates	0.9 kg/Mg of ore processed[b]						
Ore transport and storage	Fugitive particulates	2.3 kg/Mg of ore processed[b]						
Dried tailings	Fugitive particulates	0.1 kg/Mg of ore mined[c]						

[a] Ref. 80.

[b] Ref. 29, 85, 89.

[c] Ref. 87.

[d] Ref. 29.

[e] See Table 35 for characteristics.

[f] Ref. 77.

Air Emissions--

The mining and beneficiating of lead and zinc ores produce some fugitive particulate emissions. The major sources of fugitive dust emissions at mining operations are drilling, blasting, loading, and transport. Average fugitive dust emissions have been estimated at 0.1 kilogram per megagram of ore mined, based upon observations from several types of nonferrous metal mining operations (79). Cadmium emissions also occur during the extraction of zinc ore. Emissions due to wind loss from dried tailings piles are estimated at 0.1 kilograms per megagram of ore mined (87). Total emissions of cadmium to the atmosphere were estimated to be 240 Mg in 1968 (87) and 220 megagrams in 1973 (88).

The major quantity of fugitive particulates generated by the beneficiation of lead and zinc ores results from crushing and grinding operations. Average particulate emissions from crushing and grinding operations are 3.2 kilograms of ore processed; 0.9 kilograms is attributable to crushing and grinding operations and 2.3 kilograms to material transport and storage (29, 85, 89). After water is added to form an ore-water slurry, particulate emissions are negligible.

Liquid Wastes--

Mine wastewater can result from several sources including groundwater, water pumped into the mine for utility purposes (e.g., machinery cooling), hydraulic backfill operations, and infiltration of surface water. The water is pumped from the mine at a rate necessary to maintain mining operations. The required pumping rate is not related to the ore output and it varies by season. It also varies throughout the industry. Daily volume may range from hundreds of cubic meters to as much as 200,000 cubic meters (29). The characteristics of mine wastewater are a function of the ore mineralization and the local and regional geology and hydrogeology encountered. The presence of dissolved heavy metals in mine wastewater is a function of the solubilization potential of the water, and solubilization is controlled by the geologic conditions that prevail. In mines where limestone and dolomitic limestone prevail and essentially no fracturing takes place, the water has little or no solubilization potential. Acid waters occurring under these conditions would require the presence of pyrite or similar sulfur-containing materials, and they would be quickly neutralized in situ before any heavy metals are solubilized. The extent of heavy metals in solution therefore, would be minimal. Conditions associated with solubilization include (1) the presence of acid-forming minerals (e.g., pyrite); (2) limited presence of minerals with neutralizing capacity (e.g., limestone); and (3) heavily fissured ore body. Wastewaters pumped from mines possessing these conditions can contain substantial amounts of soluble salts. Other constituents that may be present in mine wastewaters include the following:

Suspended solids resulting from the blasting, crushing, and transporting of the ore.

Oils and greases resulting from spills and leakages from material-handling equipment utilized underground.

Hardness and alkalinity associated with the host rock and ore.

Natural nutrients in the subterranean water.

Dissolved salts not present in surface water.

Small quantities of unburned or partially burned explosive substances (fuel oil, ammonia nitrate, etc.).

These constituents are almost always present in mine wastewater regardless of the solubility potential of the mine. Tables 32 and 33 show the chemical characteristics of wastewaters from several mines with high solubilization potential and several with low solubility potential.

Tailings resulting from the lead/zinc flotation cells are a major source of liquid waste. These waste materials are pumped to the tailings pond. The raw wastewater from lead/zinc flotation mills is made up of the water used in the flotation circuit and housecleaning water. The waste streams consist of tailings streams (usually the underflow of the zinc rougher flotation cell), overflow from the concentrate thickeners, and filtrate from concentrate dewatering. The liquid waste produced by flotation processes varies in volume from 1000 to 16,000 cubic meters per day. In terms of quantity of ore processed, liquid waste streams from milling operations range from 330 to 1110 cubic meters per megagram (29).

The principal characteristics of the liquid wastes associated with flotation operations are as follows:

(1) Solids loadings of 25 to 50 percent (tailings).

(2) Unseparated minerals associated with the tails.

(3) Fine particles of minerals--particularly if the thickener overflow is not recirculated.

(4) Excess flotation reagents that are not associated with the mineral concentrates.

(5) Any spills of reagents that occur in the mill.

TABLE 32. RANGE OF CHEMICAL CHARACTERISTICS OF RAW MINE WATERS FROM FOUR OPERATIONS INDICATING HIGH SOLUBILIZATION POTENTIAL

Parameter	Concentration in raw mine water, mg/ℓ
pH	3.0 to 8.0[a]
Alkalinity	14.6 to 167
Hardness	178 to 967
TSS	<2 to 58
TDS	260 to 1722
COD	15.9 to 95.3
TOC	1 to 11
Oil and Grease	0 to 3
P	0.020 to 0.075
NH_3	<0.05 to 4.0
Hg	0.0001 to 0.0013 <0.0001 to 0.0001
Pb	0.1 to 0.3
Zn	1.38 to 38.0
Cu	<0.02 to 0.04
Cd	0.016 to 0.055
Cr	0.17 to 0.42
Mn	<0.02 to 57.2
Fe	0.12 to 2.5
Sulfate	48 to 775
Chloride	<0.01 to 220
Fluoride	0.06 to 0.80

[a] Value in pH units.

Source: Ref. 64.

TABLE 33. RANGE OF CHEMICAL CHARACTERISTICS OF SAMPLED RAW MINE WATER FROM THREE LEAD/ZINC MINES SHOWING LOW SOLUBILIZATION

Parameter	Concentration, mg/l
pH	7.4 to 8.1[a]
Alkalinity	180 to 196
Hardness	200 to 330
TSS	2 to 138
TDS	326 to 510
COD	<10 to 631
TOC	<1 to 4
Oil and Grease	3 to 29
P	0.03 to 0.15
NH_3	<0.05 to 1.0
Hg	<0.0001 to 0.0001
Pb	<0.2 to 4.9[b]
Zn	0.03 to 0.69
Cu	<0.02
Cd	<0.002 to 0.015
Cr	<0.02
Mn	<0.02 to 0.06
Fe	<0.02 to 0.90
Sulfate	37 to 63
Chloride	3 to 57
Fluoride	0.03 to 1.2

[a] Value in pH units.

[b] Data may reflect influence of acid stabilization on sediment.

Source: Ref. 64.

Table 34 shows the characteristics of the raw and treated waste loads of five flotation mills. This summary does not include information on a mill with total recycling or one where mill wastes are mixed with metal refining wastes in the tailings pond. Feed water for the mills is usually drawn from available mine waters; however, one mill uses water from a nearby lake. These data illustrate the wide variations caused by differences in ore mineralogy, grinding practices, and reagents.

Solid Wastes--

The major sources of solid waste generated by the lead-zinc mining industry are waste rock and tailings. Minor sources are tramp iron and wood scraps. Of the more than 14 x 10^6 megagrams of solid waste generated by the lead-zinc industry in 1974, 1.86 x 10^6 megagrams was waste rock and 12.43 x 10^6 megagrams concentrator tailings (77).

In 1974 the estimated average ratio of waste rock to ore mined was 0.10 megagram per megagram (77). Depending on the age of the mine, this ratio varied from 0 to 0.24 megagram per megagram. Little waste rock is brought to the surface in older mines because the rock is used underground for mine road construction, but the waste rock is of no use in newer mines and must be hauled to the surface. In 1974 the national average ratio of dry concentrator waste to ore mined in the lead-zinc industry was 0.69 megagram per megagram. This ratio varied from 0.26 to 0.94 megagram per megagram as a function of ore grade and percent of lead, zinc, and other metals present in the ore (77). The differences in recovery methods and disposal of by-product materials had little impact.

Control Technology

Control technologies for air emissions, liquid waste, and solid waste are covered in the following paragraphs.

Air Emissions Control--

Atmospheric emissions are not a major problem because almost all lead and zinc ores are mined underground. Drilling crushing, grinding, screening, and dried portions of tailings ponds, however, are all sources of fugitive particulates. The amounts of particulates resulting from processing operations are not significant because moisture content of lead-zinc ores is fairly high. When control is needed, manual water sprays are used to minimize fugitive particulates resulting from ore processing.

The dried portions of tailings ponds are probably the greatest source of fugitive dust. Wind contributes significantly to the fugitive dust problem by eroding the exposed surfaces; therefore reduction of surface wind speed across the source is a

TABLE 34. RANGES OF CONSTITUENTS OF WASTEWATERS AND RAW WASTE LOADS FROM FIVE SELECTED MILLS

Parameter	Range of concentration in wastewater, mg/ℓ		Range of raw waste load			
			Per unit ore milled, kg/1000 Mg		Per unit concentrate produced, kg/1000 Mg	
	lower limit	upper limit	lower limit	upper limit	lower limit	upper limit
pH[a]	7.9	8.8				
Alkalinity	26	609	410	1600	1450	10,200
Hardness	310	1760	460	4700	2290	32,500
TSS	<2	108	7	285	30	2000
TDS	670	2834	940	8500	4800	50,900
COD	71.4	1535	6	4800	30	50,000
TOC	11	35	6.35	130	30	580
Oil and grease	0	8	5	21	30	130
MBAS surfactants	0.18	3.7	0.236	13	2.05	60.7
P	0.042	0.150	0.108	0.876	0.54	2.54
Ammonia	<0.05	14	0.064	26.4	0.32	185
Hg	<0.0001	0.1	<0.00013	0.0026	<0.00168	0.130
Pb	<0.1	1.9	<0.127	6.9	<0.900	32.2
Zn	0.12	0.46	0.089	17.2	0.62	86.0
Cu	<0.02	0.36	<0.026	0.158	<0.18	1.96
Cd	0.005	0.011	0.008	0.018	<0.18	8.85
Cr	<0.02	0.67	<0.026	1.77	<0.18	1.36
Mn	<0.02	0.08	<0.026	0.290	<0.45	10.0
Fe	0.05	0.53	0.064	1.16	0.012	0.198
Cyanide	<0.01	0.03	<0.013	0.109	0.091	0.509
Sulfate	295	1825	130	4800	1260	33,700
Chloride	21	395	20	870	210	4070
Fluoride	0.13	0.26	0.370	0.944	230	5.45

[a] Value in pH units.

Source: Ref. 6-9.

logical means of reducing emissions. This can be achieved by wind breaks, surface coverings, and planting of tall grasses or grains on or adjacent to exposed surfaces. The vegetative technique is practiced most frequently, but this requires soil that supports growth (contains nutrients and moisture and is of proper texture and free of phytotoxicants). This type of soil is not always present, and natural protection against wind erosion is often insufficient.

Liquid Waste Control--

Mine pumpout water is reused in mining and processing operations whenever possible. In the more arid regions some mines produce no discharge because the water evaporates or percolates into the ground.

At many facilities mine water is used as mill process makeup water. The mine water may pass through the process first, or it may be piped to the tailing pond for use in mill flotation with recycled process water.

Acid mine water that occurs in the lead-zinc industry usually is neutralized by the addition of lime and limestone. Acid mine water containing dissolved metals may be treated effectively by combining mine water with mill tails in the tailings pond. The wastewater may be treated further by lime clarification and aeration. Lime precipitation often is used to facilitate the removal of heavy metals from wastewater by precipitation as hydroxides. This technology yields almost 100 percent reduction of several heavy metals (29).

Process water from froth flotation is normally directed to a large lagoon or pond to settle out suspended solids. Effluent from the pond is recycled to the flotation cell or to the other operations as makeup water.

Solid Waste Control--

Solid waste treatment practices in the lead-zinc industry are similar to those of the underground copper mining industry (76). Mine waste rock typically is disposed of in waste rock piles, used for construction of tailings dams and mine roads, disposed of in tailings ponds, or crushed and used as mine backfill. Tails from the concentration process are settled out in tailings ponds. When the ponds become filled with solids, they are either abandoned or the tailings are dredged or mechanically moved to form an embankment and the pond raised via a peripheral discharge of the solids.

Aside from selection of a suitable disposal site and stability control, little reclamation of solid wastes is practiced by the lead-zinc industry. Only a few companies control blowing dust or attempt to reclaim or naturalize the dump areas. When stabilization or revegetation practices are attempted, a variety of problems can develop, particularly if excessive salinity, acidity, and/or phytotoxicants are encountered. (These problems are discussed in more detail in this document in the solid waste control section for copper.)

Conclusions and Recommendations

Fugitive dust generated from waste rock disposal areas and dried tailings areas can be a major pollution problem at some lead-zinc mining operations. Because the effectiveness of the dust control provided by watering is so temporary, the use of chemical stabilizers to control dust has proven to be more cost-effective. Currently, more than 100 proprietary chemical stabilizers are available and all are reputed to control dust effectively. A comparative study of these stabilizers would be valuable.

Vegetative stabilization of tailings areas has been attempted at some facilities, but the presence of extreme acidity, salinity and/or pytotoxicants in the soil has rendered most of these attempts unsuccessful. Further research is needed in the area of soil amelioration to promote successful vegetative stabilization.

Disposal of concentrator tailings is a major area of concern in the mining and processing of lead-zinc ores. Concentrating operations generate large volumes of tailings, and scarcity of land often makes disposal of these tailings a problem. The tailings present the additional problem of often containing potentially hazardous materials such as heavy metals. Tailings usually are disposed of in tailings ponds, but most of these ponds are not lined and heavy metals may leach into and contaminate the groundwater. For this reason, therefore, techniques for the removal of heavy metals should be evaluated and/or sealing of ponds should be investigated. (Sealing existing ponds constitutes a major technological hurdle.)

Another area for possible research is the development of mechanical screening and filtering equipment to separate tailings from concentrator water. Tailings are removed from flotation water by allowing them to settle in a pond. This solid waste could be controlled more effectively if an economically feasible mechanical device were developed to continuously separate tails from the water.

The development of a reagent to replace sodium cyanide as a flotation depressant would contribute to pollution control. Cyanide can escape from tailings ponds via seepage and/or percolation and can seriously degrade any surface of groundwaters it might reach.

MAGNESIUM

Industry Description

Magnesium is the eighth most plentiful element in the earth and, in its many forms, makes up about 2.06 percent of the earth's crust (16). Although it is found in 60 or more minerals, only 4--dolomite $[Ca,Mg(CO_3)]$, magnesite $(MgCO_3)$, brucite $[Mg(OH)_2]$ and olivine $(Mg,Fe)_2(SiO_4)$ are used commercially to produce its compounds. Seawater and brines are also principal sources of magnesium, which is the third most abundant element dissolved in seawater (16).

In 1974, eight companies produced magnesium compounds from seawater in California, Delaware, Florida, Mississippi, New Jersey, and Texas; four companies from well brines in Michigan; and two companies from brines of the Great Salt Lake in Utah. One mine, located in Gabbs, Nevada, produces the only domestic magnesite. Mines in North Carolina and Washington produce olivine (16). Production statistics for magnesium appear in Section 1 of this report.

The principal uses of magnesium compounds are outlined in Table 35.

TABLE 35. USES FOR MAGNESIUM COMPOUNDS

Compound and grade	Uses
Magnesium oxide:	
Refractory grades	- Basic refractories
Caustic - calcined	- Cement, rayon, fertilizers insulation, magnesium metal, rubber, fluxes, refractories, chemical process and manufacturing, uranium processing, paper processing.
United States Pharmocopia and technical grades	- Rayon, rubber, (filler and catalyst), refractories, medicines, uranium processing, fertilizer, electrical insulation, neoprene compounds and other chemicals, cement.
Precipitated magnesium carbonate	- Insulation, rubber, pigments and paint, glass, ink, ceramics, chemicals, fertilizers.
Magnesium hydroxide	- Sugar refining, magnesium oxide, pharmaceuticals.
Magnesium chloride	- Magnesium metal, cement, ceramics, textiles, paper, chemicals

Potassium compounds, salt, and gypsum are extracted with magnesium as coproducts from sediments of seawater evaporite deposits. Sodium, lithium, iodine, and strontium compounds are obtained from sediments and near-surface brines formed by inland bodies of water. Bromine, iodine, calcium, and magnesium compounds are generally extracted from seawater and well and lake brines (16).

Process Description

In the United States, magnesium compounds are produced from seawater, well brines, and lake brines, and by open-pit mining magnesium-containing ores such as magnesite, dolomite, and brucite. Figure 27 depicts a process flow sheet for the recovery and beneficiation of magnesium.

In recovering magnesium from seawater, the seawater is pumped through a series of screens (which remove floating debris), chlorinated (to prevent growth of marine organisms) and then pumped to a flocculator tank for pretreatment (90).

In the flocculator tank, the seawater is treated with an excess of dilute caustic-lime solution. (The lime used in this process is produced from oyster shells.)

The next process step involves precipitating the magnesium hydroxide by agitation in a flocculator tank. Agitation is promoted by the addition of lime, dolomite, or caustic soda. Four sources of brines or liquors are used in this process:

- Pretreated seawater
- Bitterns from solar evaporation
- Neutralized well brines
- Untreated well brines

The insoluble magnesium hydroxide gradually settles to the bottom of the tank and is pumped to rows of filters, which dewater it so that it forms a cake of magnesium hydroxide. Magnesium hydroxide is used either to recover magnesium metal or to produce magnesium compounds.

In the solar evaporation process, seawater is pumped into ponds, which may cover an area of hundreds of hectares to a depth of 1 meter. As the seawater evaporates, moist crystals of crude sodium chloride and a magnesium-rich mother liquor (bitterns) are left behind. The mother liquor is sent to the flocculator tank, where magnesium hydroxide is precipitated.

Well brines contain a mixture of magnesium, calcium and sodium chlorides, and bromides; the actual magnesium content

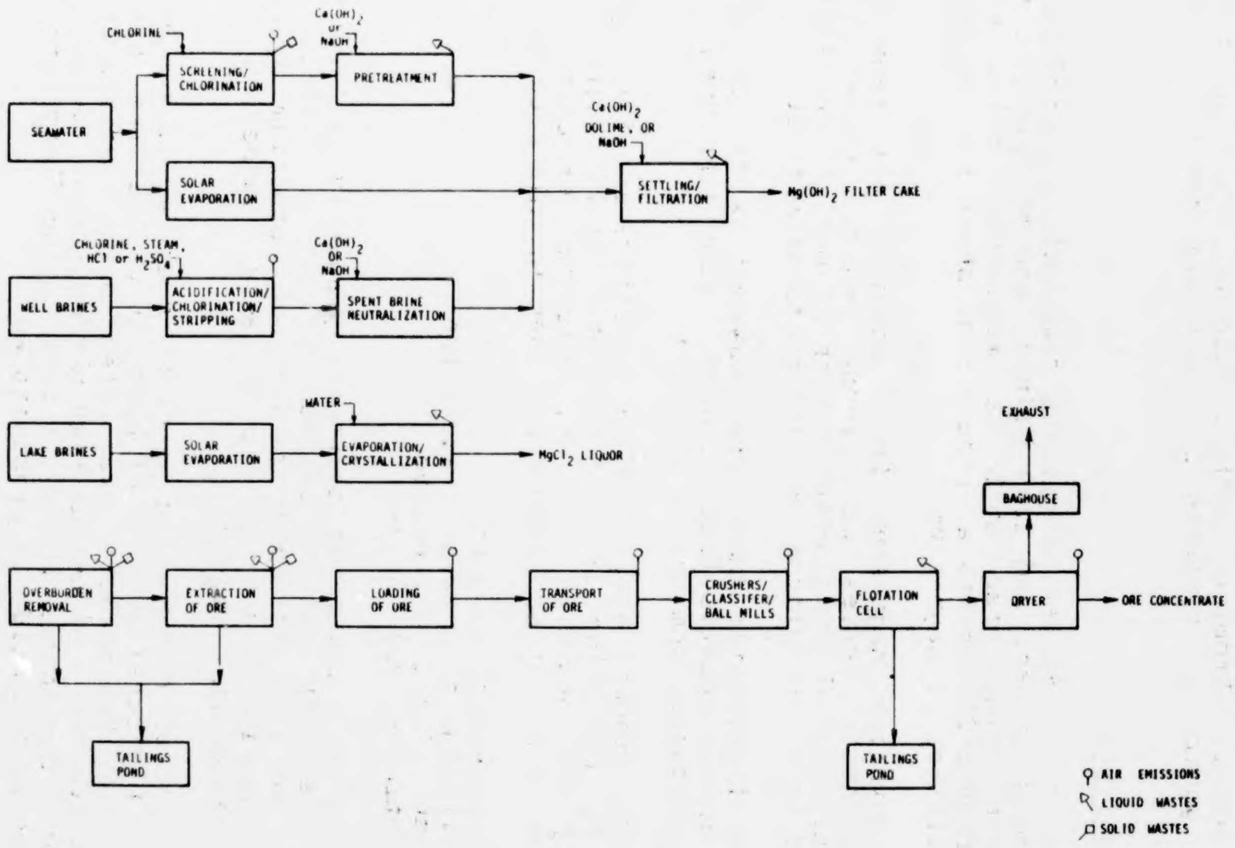
CHLORINE
SCREENING/ CHLORINATION
Ca(OH)$_2$ or NaOH
PRETREATMENT
SEAWATER
SOLAR EVAPORATION
Ca(OH)$_2$ DOLIME, OR NaOH
SETTLING/ FILTRATION
Mg(OH)$_2$ FILTER CAKE
CHLORINE, STEAM, HCl or H$_2$SO$_4$
WELL BRINES
ACIDIFICATION/ CHLORINATION/ STRIPPING
Ca(OH)$_2$ OR NaOH
SPENT BRINE NEUTRALIZATION
WATER
LAKE BRINES
SOLAR EVAPORATION
EVAPORATION/ CRYSTALLIZATION
MgCl$_2$ LIQUOR
EXHAUST
BAGHOUSE
OVERBURDEN REMOVAL
EXTRACTION OF ORE
LOADING OF ORE
TRANSPORT OF ORE
CRUSHERS/ CLASSIFER/ BALL MILLS
FLOTATION CELL
DRYER
ORE CONCENTRATE
TAILINGS POND
TAILINGS POND
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES

Figure 27. Mining and beneficiating of magnesium.

averages about 0.8 percent (91). Magnesium hydroxide is recovered from these brines by acidifying the brine with hydrochloric acid. Enough chlorine also may be added to oxidize a portion of the bromide to elemental bromine. The partially chlorinated acidified brine is sent to a packed tower, through which a countercurrent flow of steam is passed. Gaseous chlorine is injected into the tower at several points.

The bromine-stripped brine that flows from the bottom of the tower then is neutralized by adding lime or caustic soda. The solution is cooled in a heat exchanger before it is processed for recovery of magnesium hydroxide.

Brines of Michigan contain mixed crystals of sodium chloride (NaCl) and several double salts, including astrakanite ($MgSO_4.Na_2SO_4\cdot 4H_2O$), leonite ($MgSO_4\cdot K_2SO_4\cdot 4H_2O$), kainite ($KCl\cdot MgSO_4\cdot 3H_2O$) and possibly carnallite ($KClL\cdot MgCl_2\cdot 6H_2O$). Magnesium is recovered from these brines by evaporating them in solar ponds (92). The magnesium chloride bittern obtained from solar evaporation then is sent to an evaporation/crystallization process. The magnesium chloride bittern may pass through several evaporation/crystallization process steps. Vacuum crystallizers are probably utilized, although the specific crystallization paths have not been disclosed. The product from this process is a mother liquor rich in magnesium chloride.

A small percentage of the U.S. production of magnesium is obtained from magnesite, dolomite, or brucite. Ore is recovered by open-pit methods. Benches 3 meters high are advanced and blasted with ammonium nitrate primed with dynamite (16).

Ore is delivered from the mines to gyratory or jaw crushers, which reduce it to minus 12.7 centimeters in size, and then is belt-conveyed to cone crushers, which further reduce it to 1.6 to minus 1 centimeter. It is then screened and washed, passed through rake classifiers to remove slimes and ground in ball mills to 98 percent minus 100 mesh (16). From the ball mills, the ore is conveyed to flotation cells for removal of lake and serpentine impurities. The cleaned concentrate is dried in a rotary dryer.

Waste Streams

Table 36 presents a summary of multimedia wastes from the mining and beneficiating of magnesium. The following paragraphs explain in more detail the various air, liquid, and solid waste materials associated with this industry.

Air Emissions--

During chlorination of seawater, a sufficient quantity of chlorine is released to the atmosphere to be detected in the immediate vicinity by its odor (92).

TABLE 36. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF MAGNESIUM

Air			Liquid			Solid		
Source	Pollutant	emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Screening/ chlorination	Chlorine	N.A.	Pretreatment	SS	150,000 mg/ℓ	Screening	Debris and trash	N.A.
Acidification/ chlorination/stripping	Chlorine and bromine	N.A.	Settling/ filtration	NaCl	N.A.	Overburden removal	Gangue	N.A.
			Evaporation/ crystallization	NaCl	200-300 kg/Mg $MgCl_2$	Ore extraction		
Overburden removal	Particulates	N.A.	Overburden removal	N.A.	N.A.			
Ore extraction			Ore extraction	N.A.	N.A.			
Ore loading			Flotation cell	N.A.	N.A.			
Ore transport								
Crushers/ classifiers/ ball mills	Particulates	N.A.						
Dryer	Particulates	N.A.						

N.A. - Not available.

Similarly, during the chlorination/stripping process for recovery of magnesium from well brines, a gas stream containing non-condensible gases is vented to the atmosphere. This stream contains some chlorine and bromine (92).

Open-pit mining operations are a source of fugitive particulates. Other sources of particulate emissions include the crushers, ball mills, and dryers. Quantitative data on emissions from these sources have not been reported.

Liquid Wastes--

The sole waste stream from the pretreatment process is a slurry of calcium carbonate and clay particles suspended in seawater, which typically carries 150 grams total suspended solids per liter (92).

Two waste streams emanate from the settling/filtration process -- the supernatant spent brine from the settling tanks and the filtrate. These streams, identical in composition, together amount to 300 to 350 cubic meters per megagram of magnesium hydroxide (92).

A slurry of NaCl is discharged as waste stream from the evaporation/crystallization process for the recovery of magnesium chloride from lake brines. The quantity of waste is reported to range from 0.2 to 0.3 megagram per megagram of magnesium chloride (92).

The only liquid waste sources from the mining of magnesite are mine pumpout and tailings from the flotation cell.

Solid Wastes--

Floating debris and trash are collected by the screens as the seawater passes through them. The only source of solid wastes in the recovery of magnesite is the overburden removed from the mine; the quantity is not known.

Control Technology

Control technologies applied to the magnesium industry are explained in the following paragraphs.

Air Emissions Control--

Chlorine released from the chlorination process is discharged to the atmosphere without control, as is the noncondensible gas stream from the chlorination/stripping operation.

Fugitive dust emissions from the mining operation at the sole open-pit mine (in Gabbs, Nevada) are not controlled.* Neither are the emissions controlled from crushers and ball mills at this mine. Particulate emissions from the dryer, however, are controlled by a baghouse.

Liquid Waste Control--

Depending upon conditions, the waste stream from the pretreatment process may be (1) diluted with seawater and discharged into the tidal system, (2) neutralized with dilute HCl and then discharged into tidewater, or (3) discharged into diked ponds for further thickening, which qualifies the disposal as landfill operation (92).

Effluent from the settling/filtration operation is usually neutralized with waste hydrochloric acid prior to discharge. If the effluent is from seawater, the waste stream is discharged into tidewater. If it is from Michigan well brines, the stream of spent brine either is used beneficially to recover sodium and calcium chlorides or is sent to injection wells (92).

The sodium chloride slurry from evaporation/crystallization is discharged to the Great Salt Lake (92).

Mine pumpout at the open-pit mine in Nevada is sent to a tailings pond. Tailings from the flotation cell at this mining operation is also sent to the tailings pond for treatment.

Solid Waste Control--

Trash recovered from screening seawater is incinerated or buried.

Overburden and waste rock from the open-pit mine are collected and dumped on site.*

Conclusions and Recommendations

The magnesium mining and beneficiation industry causes fewer environmental impacts than most other mining and processing industries.

The following research and development programs could be undertaken: (1) Unknown contaminants in the feed streams to magnesia processing could be creating significant public health impacts. Research efforts could characterize these feed streams by assays of seawater and brines and analysis of ore concentrates. (2) Sufficient potentially hazardous chlorine is emitted to the atmosphere from the chlorination process for the smell to be detected in the immediate vicinity. Research efforts could be focused on reducing or controlling the amount of chlorine emitted to the atmosphere.

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*Telephone conversation between Vijay Patel of PEDCo and Mr. H. Ricci, Bureau of Environmental Health, State of Nevada. Carson City, Nevada. April 1977.

MERCURY

Industry Description

Although mercury is recovered almost exclusively from cinnabar (Hgs), it also has been obtained from livingstonite, metacinnabarite, and other mercury minerals. Pyrite, marcasite, and small quantities of other sulfides such as arsenic and antimony often are associated with cinnabar. A small amount of mercury is recovered also as a coproduct of gold refining (17).

At the present time the primary mercury industry in the United States is very small (93). Because of low prices and slackened demand, this industry has been declining steadily in recent years. During this same period the environmental hazards and extremely toxic nature of mercury have come under public scrutiny. (Production statistics for mercury are presented in Section 1 of this report.)

In 1974, only 12 mines were engaged in the mining of mercury ore (17). California has historically been the leading producer, followed by Nevada and Texas. Mercury has also been recovered from ore in Arizona, Alaska, Idaho, Oregon, and Washington and is recovered as a by-product from gold ore in Nevada and zinc ore in New York (46).

Mercury is used primarily in the manufacture of alkalis and chlorine and in electrical applications. Mercury and its compounds are used also as preservatives in the paint industry; in pharmaceuticals, dental supplies, and instrumentation; and for general laboratory purposes.

Process Description

Mercury ore is mined by both open-pit and underground methods. In recent years underground methods have accounted for about two-thirds of total mercury production (94). Ore grade has varied greatly, ranging from 2.25 to 100 kilograms of mercury per megagram of ore (46). The grade of ore currently mined averages 5 kilograms per megagram.*

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*Telephone conversation between Vijay Patel of PEDCo and Mr. Harold Drake, U.S. Bureau of Mines, Washington, D.C. March 1977.

As illustrated in Figure 28, the usual process of extracting mercury from cinnabar essentially involves mining and sorting of the ore, crushing, screening, and concentration.

Open-pit surface mining is accomplished by the normal drilling, blasting, digging, and loading operations. Underground mining is accomplished primarily by square-set stoping, but shrinkage and sublevel stoping methods are also used. Ore is broken by blasting, removed by scraper or mechanical loaders, and hauled to the mill for processing (76). At the mill, the ore first is crushed in a jaw crusher, then delivered by belt conveyor to the fine ore bin. The crushed ore is ground in a ball or rod mill in closed circuit with a classifier to free cinnabar from the gangue minerals.

The classified ore is sent to a flotation machine, where the frothing action of the rising air bubbles causes the mineral values to be freed from the gangue and rise to the surface of the flotation cell. The mineral concentrate is scraped off the surface and filtered through a disk filter. The dewatered concentrate is stored until needed for the.retort plant.

Waste Streams

Table 37 presents a summary of multimedia wastes from mining and beneficiating mercury. The following paragraphs explain in more detail the various air, water, and solid wastes generated by mining and beneficiating activities.

Air Emissions--

The major emissions from open-pit mines are fugitive dust and mercury vapor. From open deposits of cinnabar ore, emissions of mercury vapor through natural heat have been reported to be 0.005 kilogram per megagram of ore (76). Explosive gases are encountered in some underground mines (75).

Estimates of dust emissions from crushing, grinding, and classifying have not been reported.

Liquid Wastes--

Precipitation, runoff, and groundwater infiltration causes wastewater discharge from open-pit mining. Most open-pit mercury mines are in arid regions, however, so very little liquid waste is discharged. Groundwater infiltration is the primary source of water in underground mines. No specific information is available concerning discharge from underground mines. It is expected, however, that the particular metals present in underground mine discharge and the extent of their dissolution depend on the geology and mineralogy of the ore body and on the oxidation potential and pH prevailing within the mine.

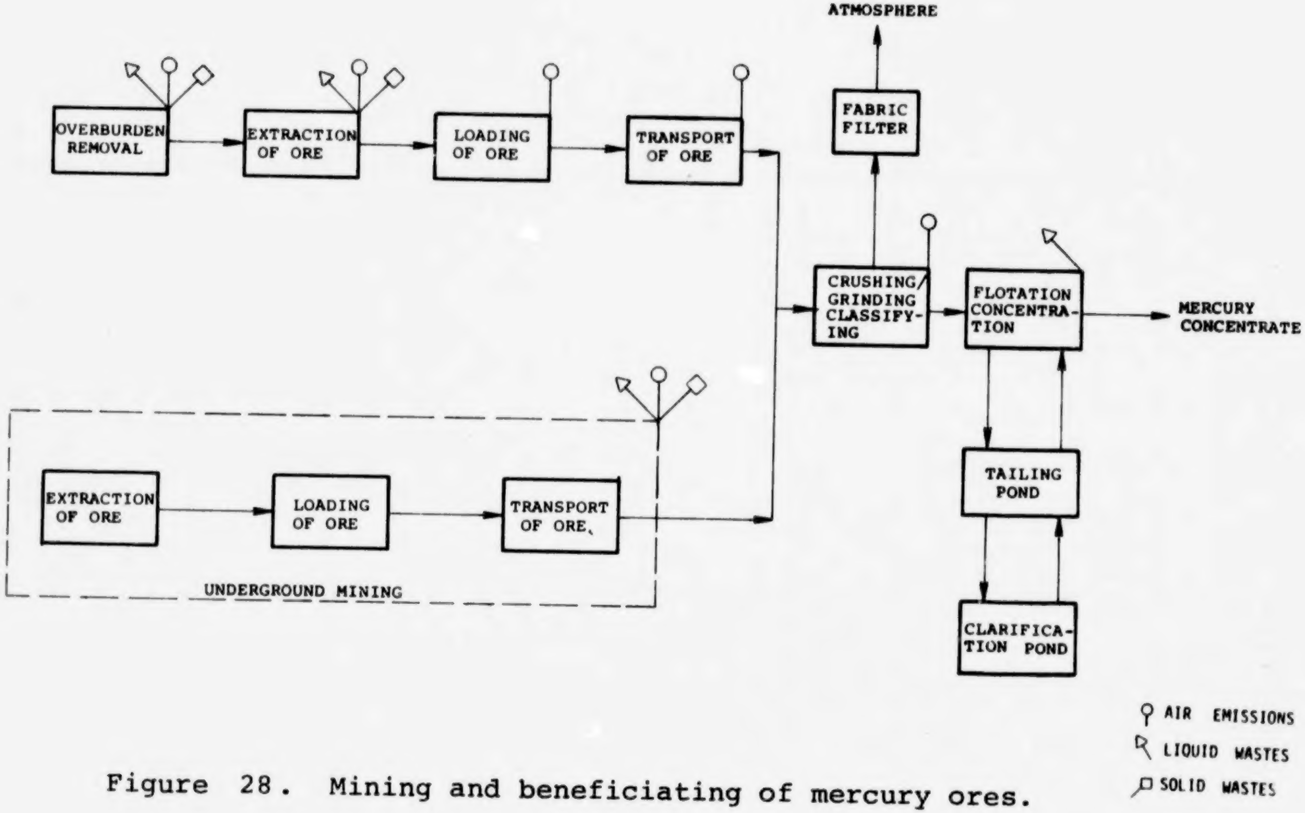
ATMOSPHERE
FABRIC FILTER
OVERBURDEN REMOVAL
EXTRACTION OF ORE
LOADING OF ORE
TRANSPORT OF ORE
CRUSHING/ GRINDING CLASSIFY-ING
FLOTATION CONCENTRA-TION
MERCURY CONCENTRATE
EXTRACTION OF ORE
LOADING OF ORE
TRANSPORT OF ORE
UNDERGROUND MINING
TAILING POND
CLARIFICA-TION POND
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES

Figure 28. Mining and beneficiating of mercury ores.

TABLE 37. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF MERCURY

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal	Fugitive particulates and mercury vapor	Not available for particulates; 0.005 kg/Mg of ore for mercury vapor[a]	Overburden removal	N.A.	N.A.	Overburden removal	Gangue	N.A.
Extraction of ore			Extraction of ore			Extraction of ore		
Loading of ore			Underground mining	N.A.	N.A.	Underground mining	Gangue	N.A.
Transport of ore			Flotation concentration	N.A.	N.A.			
Underground mining	Fugitive particulates	N.A.						
Crushing/ grinding/ classifying	Particulates	N.A.						

[a] Ref. 76.

N.A. - Not available.

Wastewater emanating from mills employing froth flotation is likely to be high in suspended solids loadings. Some of the flotation reagents may also be washed out with the tailings. Although the total dissolved solids loading may not be extremely high, a relatively high dissolved heavy-metal concentration may result from the highly mineralized ore being processed. Also, depending upon the process conditions, the waste stream may have a high or low pH, which is of concern because of its effect on the solubility of the waste constituents (29).

Solid Wastes--

The quantity of overburden and gangue removed from open-pit and underground mines has not been reported. The predominant minerals in the waste rock are silica and carbonate minerals, and some deposits contain pyrite. Mercasite, stibnite, and orpiment also occur, but rarely (76).

Control Technology

The following paragraphs contain explanations of the control techniques as applied to air, liquid and solid waste.

Air Emissions Control--

Dust from open-pit and underground mines is controlled by conventional techniques such as applying wet drilling methods and treating haul roads with water. Mercury vapor emissions are not controlled and may create a potential health hazard.

Control of emissions from crushing operations is achieved by enclosing the crusher and venting emissions to a control device such as a baghouse.* The efficiency of the baghouse has not been reported.

Liquid Waste Control--

Since most open-pit mines are located in arid regions of the country (Nevada and California), no discharge of liquid wastes has been reported from these mines (29). At present no large-scale underground mercury mines are operating in the United States, so no data were available on effluents from this source.

One mill (which recently began operation) proposed to use a recycle system in which the effluent from the flotation cell first would be discharged into a tailings pond, then into a clarification pond. The clarified effluent would be recycled to the flotation cell, and no discharge was expected to result (29).

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*Telephone conversation between Vijay Patel of PEDCo and Mr. Harold Drake, U.S. Bureau of Mines, Washington, D.C. March 1977.

Solid Waste Control--

Currently, all solid wastes from open-pit mines are either ploughed back into the mine site or are used for tailings pond dam construction. The method of disposing of solid wastes from underground mines is not known.*

Conclusions and Recommendations

The mercury industry in the United States is comparatively small in terms of production. Remote locations and arid climates tend to minimize the environmental impacts of mercury mines.

The most significant environmental problem is the control of hazardous mercury vapor from open deposits.

Most wastewater from mining and processing of the ore is recycled; however, the potential is great for release of mercury to the environment through impoundments. For this reason efficient methods for the removal of mercury from water should be developed.

RARE EARTH ELEMENTS

Industry Description

Rare earth elements, sometimes known as lanthanides, consist of a series of 15 chemically similar elements with atomic numbers 57 through 71. Yttrium, atomic number 39, is also often included in the group because of its similar properties and frequent occurrence in association with lanthanides. The principal mineral sources of the rare earth metals are bastnaesite ($CeFCO_3$) and monazite (Ce, La, Th, Y) PO_4 (29).

In 1974 only three U.S. companies mined rare earth oxides, one each in California, Georgia, and Florida. The California company mined more than 95 percent of the total output, whereas the other two recovered monazite as a by-product while mining pleistocene beach sands for titanium and zirconium minerals (18).

Table 38 lists many of the uses of the rare earths. Very few of these consume significant quantities of rare earth.

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*Telephone conversation between Vijay Patel of PEDCo and Mr. Harold, U.S. Bureau of Mines, Washington, D.C. March 1977.

TABLE 38. USES OF RARE EARTH ELEMENTS

Metallurgy	As alloying agents in iron and steel, superalloys, and pyrophoric alloys; lighter flints; pure metals for research.
Glass	In polishing, decolorizing, coloring; as filters; in optical and photochromic glass (camera lenses).
Ceramics	As colorants for enamels and glazes; in coatings, refractories, and stabilizers.
Illumination	In carbon arcs; lasers; fluorescent and mercury vapor lamps; phosphors (X-ray intensifiers, display, and color television).
Electronic	In capacitors, cathodes, electrodes, semiconductors, thermistors, magnets, computer components (garnets and ferrites) and memories.
Nuclear	In control rods; as burnable poisons; as dilutants; in shielding, radioactive heat and power sources, detectors, and counters.
Chemical	As catalysts; in pharmaceutical, water treatment, chemical processing and analysis; as shift reagents and tags in organic and biological chemistry.
Other	In jewelry, photography, lubrication, thermometers, paint and ink dryers, textiles.

Virtually all of the monazite from beach sands and river gravel now is a by-product of mining ilmenite, rutile, tin, and zircon. Other minerals often found in association with monazite include xenotime, gold, staurolite, sillimanite, tourmaline, garnet, kyanite, andalusite, spinel, and corundum (18).

Process Description

The California Mountain Pass Mine recovers the rare earth mineral, bastnaesite, as a primary product. The ore, which is recovered by open-pit mining, contains 7 to 10 percent rare earth oxides. These oxides are upgraded during beneficiation to a mineral concentrate containing more than 60 percent mineral. Monazite in Georgia and Florida, on the other hand, is recovered predominantly as a by-product during the dredge-mining of sand placers for their titanium mineral content. (For details on the dredging of sand placers for their titanium mineral content refer to Section 5.)

Very little overburden removal now takes place at the Mountain Pass Mine, but future stripping ratios may approach 5:1.* Ore is extracted by blasting, then loaded into trucks (by power shovels) and hauled to the mill. At the mill the ore is crushed, ground, and classified. Ore is concentrated at the mill at a rate of 2721 megagrams per day (46). (See Figure 29.)

The crushing, grinding, and classifier operations consist of a primary jaw crusher in series with a cone crusher, from which a 1.6 centimeter feed passes to a rod mill. The rod mill produces a minus-0.3-centimeter material, which is then fed to a classifier in closed circuit with a conical ball mill. The classifier overflow is sent to a series of three heating agitators, which heat the pulp by stages to 95°C, then to a fourth agitator, which cools the slurry to 60°C before pumping it to rougher flotation. Heating is necessary to condition the bastnasite for flotation (46).

Flotation is initiated in four Fagergren and eight Agitair rougher machines, which produce a tailing for discard. Barite is depressed during flotation, and the froth is cleaned in five stages of flotation cells. Froth from each cell advances to the next stage, and tailings are recycled countercurrently to the preceding cell. Concentrate from the final flotation cell contains 63 percent rare earth oxides.

Leaching the concentrate with 10 percent hydrochloric acid removes calcium and strontium carbonates and raises the grade of the rare earth oxide to 72 percent (76). The concentrate is then sent to a chemical refining facility for further concentration.

Waste Streams

Table 39 presents a summary of multimedia wastes from the mining and beneficiation of rare earth minerals. The following paragraphs explain in more detail the various air, liquid, and solid wastes associated with this industry.

Air Emissions--

Fugitive dust is the primary particulate emission from open-pit mining. Dust particles are also generated by the crush-

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*Telephone conversation between Vijay Patel of PEDCo and Mr. J. H. Jolly, Bureau of Mines, Washington, D.C. March 1977.

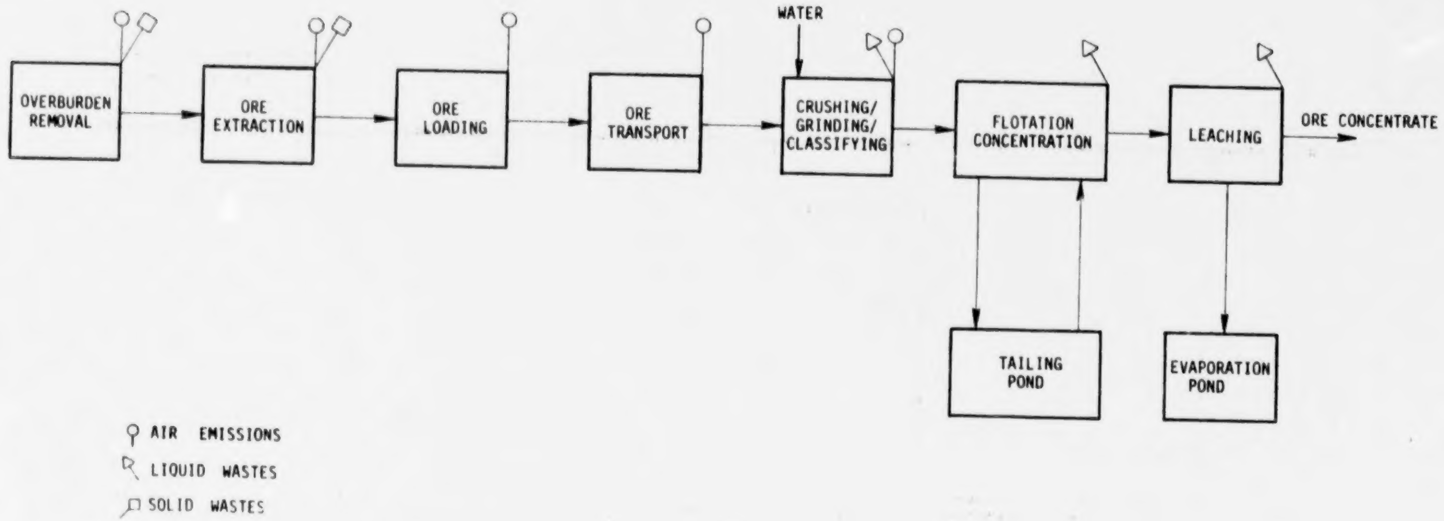
OVERBURDEN REMOVAL
ORE EXTRACTION
ORE LOADING
ORE TRANSPORT
WATER
CRUSHING/ GRINDING/ CLASSIFYING
FLOTATION CONCENTRATION
LEACHING
ORE CONCENTRATE
TAILING POND
EVAPORATION POND
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES

Figure 29 . Mining and beneficiating of rare earth elements.

TABLE 39. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF RARE-EARTH ORES

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal			Crushing/ grinding/ classifying	N.A.	N.A.	Overburden removal	Surface soil and rock	N.A.
Ore extraction	Fugitive particulates	N.A.	Flotation concentration	a	a	Ore extraction	Waste rock	
Ore loading								
Ore transport			Leaching	$CaCO_3$	N.A.			
				$SrCO_3$	N.A.			
				$BaSO_4$	N.A.			
Crushing/ grinding/ classifying	Particulates	N.A.		Cl^-	54,000 mg/ℓ			

[a] See Table 40.

N.A. - Not available.

ing operation. Quantities of particulate emissions from these sources have not been reported.

Liquid Wastes--

No liquid wastes are discharged from the Mountain Pass open-pit mining operation (76), and the only waste stream from the grinding-classifying process results from spills. Raw wastes are, however, discharged at a rate of 1.96 cubic meters per minute from the flotation circuit. Table 40 shows the characteristics of this waste stream.

TABLE 40. CHEMICAL COMPOSITION OF RAW WASTEWATER FROM A FLOTATION MILL

Parameter	Concentration (mg/ℓ)
pH	9.02[a]
TDS	14,476
TSS	360,000
TOC	3,100
Cr	0.35
Total Mn	0.5
V	<0.3
Fluoride	365

[a] Value in pH units.

Source: Ref. 29.

The leaching process produces a waste stream that contains dissolved calcite ($CaCO_3$), strontianite ($SrCO_3$), and barite ($BaSO_4$) from the concentrates. Chlorides in solution are extremely high, 54,000 milligrams per liter. Leach waters are impounded with wastewater from the flotation process (76).

Solid Wastes--

The only solid waste generated by the open-pit mining operation is waste rock. The quantity has not been reported.

As discussed previously in the liquid waste section, leaching processes generate solid waste in the form of suspended solids in a liquid (slurry).

Control Technology

Control technology applied to the mining and beneficiation of rare earth minerals is explained in the following paragraphs.

Air Emissions Control--

Water spraying is used to control dust from the open-pit mining operation and also the crushing operation (75).

Liquid Waste Control--

Tailings from the flotation concentration process are discharged to a tailings pond, and the clarified pond water is recycled back into the flotation circuit. The treated recycle water from the pond achieves the following removal efficiencies (29): 96 percent total suspended solids, 35 percent total dissolved solids, 55 percent total organic carbon, 92 percent chromium, and 85 percent fluoride.

Process wastes from the leach circuit are separately discharged to an evaporation pond (29).

Solid Waste Control--

The amount of overburden at the Mountain Pass Mine is insignificant. The comparatively small quantities of waste rock are disposed of on the mine site.*

Conclusions and Recommendations

The rare earth mineral mining industry is not considered a source of adverse environmental impacts.

One possible area of research involves the recycling or disposal of the large quantities of overburden waste that rare earth mining is expected to produce as the industry expands in the future.

SILVER

Industry Description

The chief silver minerals of economic importance are native silver (Ag), argentite (Ag_2S), cerargyrite ($AgC\ell$), polybasite ($Ag_{16}Sb_2S_{11}$), prousite (Ag_3AsS_3), pyrargyrite (Ag_3SbS_3), stephanite (Ag_5bS_4), and tetrahedrite ($Cu_3(Sb,Ag)S_3$). Silver is most commonly associated with lead and copper, but it is also recovered as a by-product from some gold or zinc ores (19).

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*Telephone conversation between Vijay Patel of PEDCo and Mr. J. H. Jolly, Bureau of Mines, Washington, D.C. March 1977.

The supply-demand relationship of silver is more complicated than that of other metals because of such factors as the use of silver for monetary purposes and the sizable speculative and investment market. Virtually all of the ore mined in the United States is refined here, but only about half of the U.S. silver refinery production comes from domestic ores. Secondary refining, changes in industry stocks, and treasury releases provide a major portion of the silver supply (19).

In the United States, new silver is produced almost entirely from low-grade, complex sulfide ores. About 25 percent is produced from ores in which silver is the chief value and lead, zinc, and/or copper are by-products. The other 75 percent is produced from ores in which lead, zinc, and copper are the principal values and silver is a by-product (29).

The United States has about 25 percent of the estimated 704,000 megagrams of silver reserves in the world. These reserves are believed to be in the same ratio as current production--25 percent in ores where silver is the main product, 75 percent in ores where silver is a by-product (19).

Almost 99 percent of the ores mined principally for silver come from the Coeur d' Alene district in Idaho, and about 20 percent of the silver mined as a by-product also comes from this area. This output makes the Coeur d'Alene district the source of almost 40 percent of all silver produced in the United States. Other silver by-product mines are located in Arizona, Nevada, Montana, and Utah (95). Minor quantities of silver are also mined in Alaska, California, Colorado, Michigan, Missouri, New Mexico, and South Dakota (29).

Silver is used primarily in photography, silverware, and electrical and electronic equipment. It is also used in jewelry, arts and crafts, solders, brazing alloys, medicinal compounds, and catalysts (95).

Silver mining yields many coproducts and by-products. For example, most of the antimony produced in the United States is mined as a by-product of silver. Other nonferrous metal coproducts or by-products of silver include bismuth, copper, gold, lead, platinum group metals, and zinc. Section 2 presents production statistics for silver and associated metals.

Process Description

Silver is mined by open-pit methods and subsurface shafts and drifts. The method varies from one ore body to another and depends on such factors as steepness of the terrain, availability of transportation, reserves, ore body or vein shape, depth of deposit, character of the host rock, and economic factors peculiar to the individual mine. In the United States most silver is mined underground. Figure 30 shows a composite flow diagram of the mining and beneficiating of silver ores.

Only a small percentage of U.S. silver is mined from placer deposits. These deposits are mined by excavating silver-bearing gravel and sand, then washing and screening it to remove clay, other soluable materials, and oversize gravel. The undersize from the screening is sent to a jig for gravity separation.

Following gravity separation, the silver ore is chemically separated by either amalgamation or flotation and cyanidation. After these processes, it is still necessary to refine the silver concentrate to a purity level generally exceeding 99.9 percent. Less than 1 percent of the current domestic production of silver is recovered by amalgamation or flotation/cyanidation processes (29). A more complete discussion of these processes is contained in Section 5, Gold.

Silver ores are recovered from open-pit mines in conjunction with the mining of other metals. Overburden depth can be considerable, and at one mine it exceeds 150 meters (76). After the overburden is removed, mining operations consist of drilling blasting holes, blasting of the ore, loading it into trucks or rail cars, and transporting it to the concentrator. Occasionally, blasting is not required, and the ore is merely "ripped" by bulldozers, then loaded (76).

In underground mining, various techniques are used to remove the ore from deep deposits, the choice depending on the characteristics of the ore body. Caving and supported stoping are the primary methods. The ore is hauled to the beneficiation site by rail, truck, or belt conveyor.

The first beneficiation step involves crushing the complex silver ore. This is a dry (natural moisture content) process, but all additional beneficiation steps are performed wet. The ore next undergoes wet grinding, followed by classification. Oversize material from the classifier is returned for regrinding; undersize ore is sent to a flotation unit for separation. Almost all the ores require fine grinding to liberate the sulfide minerals from one another and from the gangue.

Selective froth flotation is the most effective method of beneficiating complex silver sulfide ores. Essentially, a combination of various reagents is used to cause the desired sulfide mineral to float and be collected in the froth while other minerals and the gangue sink. This process or series of processes is used to separate silver from copper, gold, lead, zinc, and various other metals.

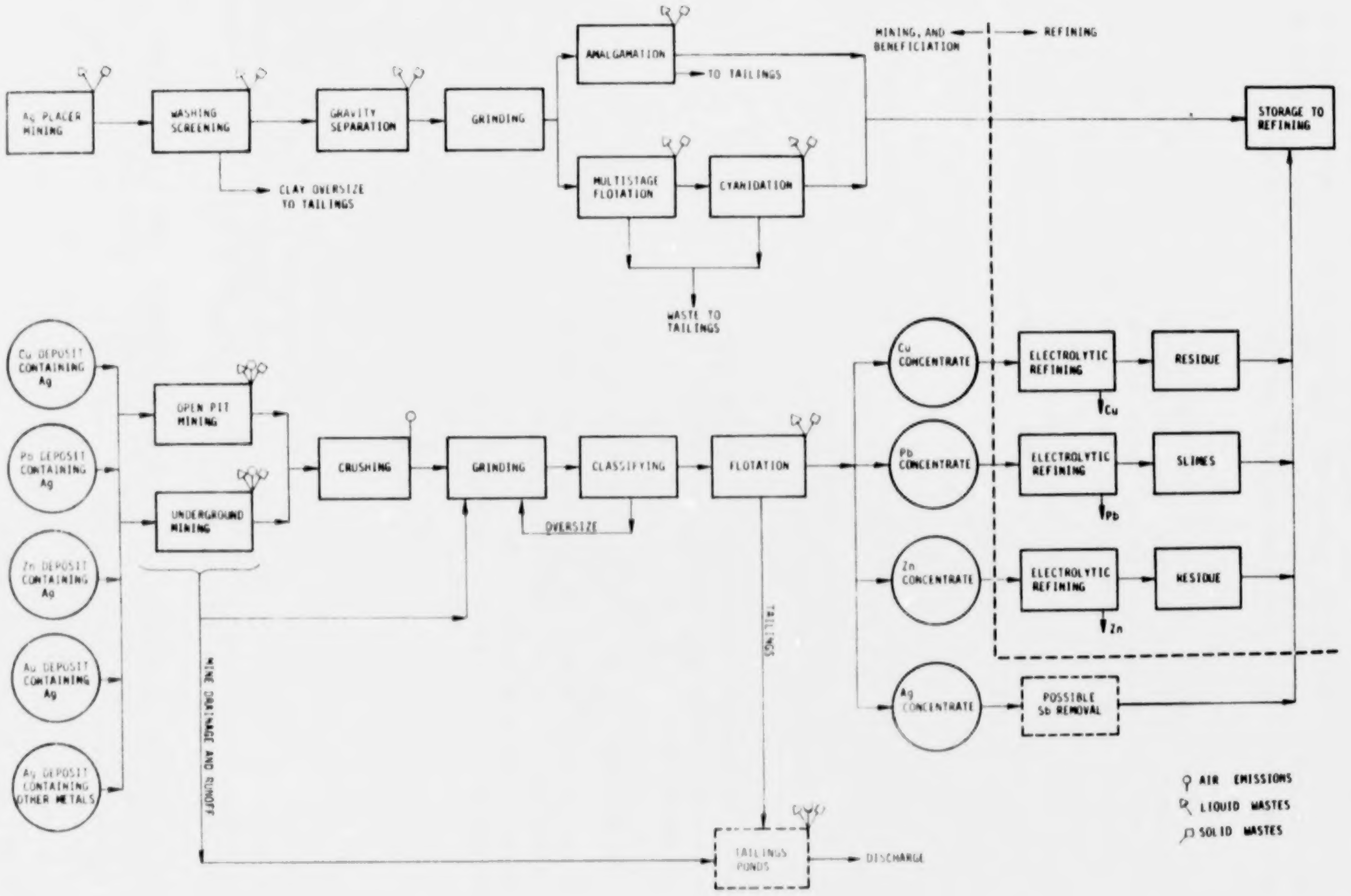
Ag PLACER MINING
WASHING SCREENING
CLAY OVERSIZE TO TAILINGS
GRAVITY SEPARATION
GRINDING
AMALGAMATION
TO TAILINGS
MULTISTAGE FLOTATION
CYANIDATION
WASTE TO TAILINGS
MINING, AND BENEFICIATION
REFINING
STORAGE TO REFINING
Cu DEPOSIT CONTAINING Ag
Pb DEPOSIT CONTAINING Ag
Zn DEPOSIT CONTAINING Ag
Au DEPOSIT CONTAINING Ag
Ag DEPOSIT CONTAINING OTHER METALS
OPEN PIT MINING
UNDERGROUND MINING
CRUSHING
GRINDING
CLASSIFYING
OVERSIZE
FLOTATION
TAILINGS
MINE DRAINAGE AND RUNOFF
TAILINGS PONDS
DISCHARGE
Cu CONCENTRATE
Pb CONCENTRATE
Zn CONCENTRATE
Ag CONCENTRATE
ELECTROLYTIC REFINING
Cu
ELECTROLYTIC REFINING
Pb
ELECTROLYTIC REFINING
Zn
POSSIBLE Sb REMOVAL
RESIDUE
SLIMES
RESIDUE
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES

Figure 30. Mining and beneficiating of silver.

Silver is recovered primarily from the mineral tetrahedrite, $(Cu, Fe, Zn, Ag)_{12}Sb_4S_{12}$. The tetrahedrite concentrate from the flotation unit will usually contain approximately 25 to 32 percent copper, 2 to 4 percent silver, and up to 18 percent antimony (which may or may not be extracted prior to shipment to the smelter).

Although flotation is used to separate silver from complex ores, recoverable silver still remains in the separated metal concentrates (i.e., copper, lead, zinc). Also, the silver concentration in the complex ore often is not high enough to justify flotation separation, in which case the silver is separated by electrolytic refining of the base metal concentrate. In all cases, further refining of the silver is necessary to attain the marketable purity of 99.9 percent.

Waste Streams

Table 41 presents a summary of multimedia wastes from the mining and beneficiating of silver ores. The following paragraphs contain more detailed information on the various air, liquid, and solid waste associated with this industry.

Air Emissions--

Mining and beneficiation of placer deposits do not generate air emissions because all the processes are carried out in the presence of water.

Air emissions from the mining and beneficiation of other silver ores are mostly fugitive dust. Estimates and characteristics of emissions from open-pit and underground silver mines are not available. One reference did estimate the total silver metal emissions from mining and beneficiating silver ores at less than 2 megagrams per year nationally (96). No specific air emission values are available for the crushing of silver ores. The wide variety of ores containing silver would cause any estimates of emissions from ore crushing to vary greatly.

Liquid Wastes--

Placer mining and beneficiation processes use large quantities of water. Although no specific data are available on the characteristics of and concentrations in the effluent from washing, screening, and gravity separation, this effluent is known to have a high suspended solids content.

Effluent from grinding and amalgamation is also high in suspended solids. Mercury is the prominent agent used in this process; therefore, the effluent is potentially toxic. Cyanide leaching results in high levels of soluble metals. Both the cyanide and heavy metals are potentially toxic; however, this

TABLE 41. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF SILVER ORES

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant/ parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Open-pit mining	Particulates		Placer mining	TDS, TSS		Placer mining	Gangue	N.A.
Underground mining	Particulates	Negligible	Washing	Sand, clay		Washing	Sand, clay	N.A.
Crushing	Particulates		Gravity separation	TDS, TSS		Gravity separation	Tailings	N.A.
Tailings pond	Particulates		Cyanidation	CN, heavy metals		Cyanidation	Heavy metals	N.A.
			Amalgamation	Hg		Amalgamation	Hg, tailings	N.A.
			Flotation	TSS	1.859 kg/Mg ore[b]	Open pit mining	Overburden, gangue	N.A.
			Flotation	CN	0.00019 kg/Mg ore[b]	Underground mining	Gangue	N.A.
			Flotation	Cd	0.00038 kg/Mg ore[b]	Flotation	Tailings	N.A.
			Flotation	Cu	0.0016 kg/Mg ore[b]	Tailings	Tailings	N.A.
			Flotation	Hg	0.00063 kg/Mg ore[b]			
			Flotation	Pb	0.0027 kg/Mg ore[b]			
			Flotation	Zn	0.0024 kg/Mg ore[b]			
				TSS	0.0085 kg/Mg ore[c]			
				Cu	0.00034 kg/Mg ore[c]			
			Underground mining	Pb	0.00069 kg/Mg ore[c]			
			Open-pit mining	Zn	0.0024 kg/Mg ore[c]			
				Hg	0.000014 kg/Mg ore[c]			
			Tailings	TSS	0.069 kg/Mg ore[d]			
			Tailings	Cu	0.00031-0.00017 kg/Mg ore[d]			
			Tailings	Pb	0.00065-0.00034 kg/Mg ore[d]			
			Tailings	Zn	0.0021-0.0017 kg/Mg ore[d]			
			Tailings	Hg	0.000010-0.0000034 kg/Mg ore[d]			

[a] For more complete information, see Section 5.

[b] Ref. 46. Hypothetical values.

[c] Ref. 46. Untreated for hypothetical mine.

[d] Ref. 46. Outflow from tailings - range from settling to lime treatment.

N.A. - Not available.

does not create a great problem because less than 1 percent of domestic production of silver is currently recovered by amalgamation or cyanidation (46).

The leading silver producers (especially in Idaho) usually recover the ore by underground mining. Some of the water from mine pump-out is used in beneficiating operations; the rest is sometimes discharged directly into streams (46).

Silver ores are recovered less frequently by open-pit mining. The source of any pit discharge from open-pit mining, results from precipitation, runoff, and groundwater infiltration into the pit. No specific data are available on the pump-out from open-pit silver mines.

Table 41 presents wastewater discharge rates for a hypothetical silver mine. The figures are based on an arithmetic average of five large silver mines (29). These figures represent a combination of water from runoff, pumpout, and all processes other than flotation. Discharge rates for mills using flotation are shown separately. Froth flotation is the most common process now used in beneficiation. The volumes of the waste streams discharging from mills processing silver ore range from 1499 to 3161 cubic meters per day (29). The amount of solids contained in these waste streams vary from 272 to 1542 megagrams per day.

Solid Wastes--

The quantity of solid waste rock from placer mining is probably less than that generated by either open-pit or underground mining (46). However, no specific solid waste data are available for placer silver mining.

Washing to remove sand and clay and gravity separation do generate solid waste, which is sent to tailings. Published data have not estimated the exact makeup of this waste or quantity generated.

Because of the small quantity of silver processed by either cyanidation or amalgamation, no information has been published on the quantity of solid waste produced by these beneficiating processes.

Open-pit mining of silver ore can generate sizable solid wastes. Because silver is such a valuable element, it is feasible to remove large quantities of overburden to obtain relatively small quantities of ore. For the same reason, large quantities of gangue may also be generated once the ore body is reached. No specific solid waste data are available, however, to estimate the quantity of overburden and gangue generated by open-pit silver ore mining.

Typically, less solid waste is generated by underground mining than open-pit mining. Little or no overburden is generated, and because the higher cost of underground mining limits this means of silver recovery to only the richer deposits, less gangue also is generated than with open-pit mining. Again, no data are available on which to base estimates of the quantity of waste generated by underground silver mining.

Most silver ore is beneficiated by the froth flotation process. Selective froth flotation can effectively and efficiently beneficiate almost any type and grade of sulfide ore. The quantity of tailings generated by flotation of silver ores depends, of course, on the concentration of silver and other metals present in the ore. No composite figure is available to estimate the quantity of tailings for a typical silver beneficiation process.

Control Technology

Much the same control technology is used in the silver mining industry as in other mining industries. The following paragraphs explain these controls as applied to air, liquid, and solid waste.

Air Emissions Control--

Overburden removal, ore extraction, and ore transport are among the most variable fugitive dust sources in open-pit mining. They are also among the largest particulate sources. Dust and particulate emissions from these operations vary with the composition, texture, and moisture content of the material; excavation procedures; equipment employed; etc. A literature search yielded no controls that were specific to the open-pit mining of silver ore.

Visits to two underground silver mines lead us to believe that control of air emissions from mine ventilation is unnecessary.

No information was found on specific emission controls for the silver ore crushing process. Particulate emissions from this source can be controlled by any of numerous conventional methods.

Air emissions from tailings occur only when the tailings pond becomes dry (i.e., when the pond is no longer used). Intentional or natural formation of a crust on the surface of the pond can reduce emissions from this source by as much as 80 percent (65).

Liquid Waste Control--

Wastewater from placer mining, washing, and gravity separation is discharged into a tailings pond, where suspended solids are allowed to settle out. An alternative technology is to pump the wastewater from the dredging operations to a tailings disposal area for filtration through sands and gravels. It may be necessary to enhance the settling of suspended solids by the addition of settling aids when using this method (29).

Mill water from amalgamation and cyanidation is also discharged into a tailings pond. Because of the small quantity of silver beneficiated by cyanidation (less than 1%), no information was found on controls used with these processes. Spillage of the liquor containing cyanide is always a potential hazard, and improper handling could have significant environmental impact (46).

It is possible to eliminate discharge of liquid wastes from cyanidation of silver by either recycling or total impoundment of the process water. To implement this technology, recycling of process reagents may be necessary both to achieve economy in reagent use and to avoid high concentrations of cyanide in recycled process water (29).

Only one operation now utilizes amalgamation to recover silver. Two sedimentation ponds are now used to control wastewater, but they are inadequate for proper metal removal. Chemical precipitation of the metals would solve this control problem (29).

Water from runoff, mine pumpout, and other processes (except flotation) should be discharged into a tailings pond for settling before it is released into a stream. According to one reference, a typical silver mining operation has little or no effluent treatment or control (29). Estimated control efficiencies for treating an average silver mine effluent by sedimentation are as follows: total suspended solids, 20 percent; copper, 10 percent; lead, 5 percent; zinc, 14 percent; mercury, 25 percent. When lime precipitation is used in conjunction with the settling, control efficiencies are increased by the following additional percentages: copper, 45 percent; zinc, 17 percent; and mercury, 33 percent. When sulfide precipitation and close control are practiced in addition, both lead and mercury levels are reduced an additional 40 percent (29).

Solid Waste Control--

Because silver has such a high value, ore bodies containing only small concentrations of silver are mined. The silver is almost completely extracted, but this leaves huge quantities of overburden, gangue, and tailings to be disposed of.

Because more than 300 U.S. mines produce silver from a wide variety of ores, it is difficult to quantify the solid waste from a silver mine. Backfilling of a mined-out area or an underground mine is a good disposal method for solid waste generated by any of the mining processess. Even the tailings can be disposed of by dredging and backfilling. Theoretically, all of the solid waste generated could be reburied and revegetated, but Federal, state, and local regulations will probably determine how much is actually reclaimed.

Solid waste generated by washing, gravity separation, cyanidation, amalgamation, and flotation is generally sent to a tailings pond, where most of the solids settle out. Because all these solid wastes use water as the separation and transport medium, the ultimate disposal method is tied to whatever control is used on the liquid waste. Liquid waste control invariably involves a tailings pond; thus, solid waste control involves the ultimate burial and revegetation of the tailings.

Conclusions and Recommendations

Liquid wastes create the largest pollution problem in the silver mining industry. This problem is magnified by the fact that most silver mines in the United States are in areas with irregular terrain. Irregular terrain can make treatment by tailings ponds difficult at best.

Also, because most silver is mined in conjunction with several other minerals, separation is accomplished by a series of flotation cells, and many reagents are accumulated in the final wastewater. This multiciplity of reagents makes the recycling of flotation water difficult, if not impossible.

This points to an area where research is needed. Either an economical way must be found to recover or separate the reagents from the wastewater or degradable reagents must be used that naturally deteriorate after a short period of time. Either of these would make total recycling of water possible in dry mining areas.

Another area for research is the possibility of combining liquid wastes from several adjacent mines into one larger reverse-osmosis treatment facility. This would be particularly attractive in areas where space limitations make large tailings ponds expensive.

TITANIUM

Industry Description

Rutile and ilmenite are the principal titanium-bearing minerals. Rutile, or titanium dioxide, is the most desirable source. It contains above 50 percent titanium after beneficiation. This mineral is not abundant, however, and very little is mined in the United States. Ilmenite, or iron titanium oxide, is more abundant, but must be processed more to recover the titanium oxide. Ilmenite deposits occur in sand and rock (97).

Economically recoverable titanium resources of the United States are known to occur as 1) ilmenite rock deposits in New York and Virginia; 2) ilmenite beach sands in Florida, New Jersey, and Georgia; 3) rutile rock deposits in Virginia; and 4) rutile sand deposits in Florida, South Carolina, Tennessee, and Georgia. Additional, none economically recoverable ilmenite resources are known to exist in California, Colorado, Minnesota, Montana, New York, Rhode Island, Wyoming, Oregon, and Oklahoma (95).

About 70 percent of the ilmenite produced in the United States comes from three mines, two in Florida and one in New York. The other 30 percent comes from two mines in New Jersey and two more mines in Florida. Rutile associated with ilmenite in Southeastern sand deposits is not shipped separately except from one Florida mine. The rest of the world's output of ilmenite comes mostly from Canada, Norway, Australia, and the U.S.S.R. About 96 percent of the world's rutile comes from Australia (20). The United States produced an estimated 580,480 megagrams of ilmenite in 1975 (98), and about 9070 megagrams of rutile in 1974 (99).

Domestic ilmenite and rutile and imported ilmenite are used to manufacture TiO_2 pigment and other TiO_2 products. Titanium metal is either imported or produced from imported rutile. Zirconium, hafnium, and rare earth elements (discussed in separate sections of this report) are by-products and coproducts of titanium processing.

Process Description

Titanium minerals of economic importance are contained in rock and sand deposits. The ilmenite from rock deposits and some sand deposits usually contains 35 to 55 percent TiO_2. Some sand deposits, however, yield altered ilmenite (leucoxene), which contains 60 percent or more TiO_2, as well as rutile, which contains 90 percent or more TiO_2 (99).

The method of mining and beneficiating titanium minerals depends on whether the ore is deposited in sand or rock.

Beach Sand Deposits--

Heavy mineral beach sand (placer) deposits occurring in Florida, Georgia, and New Jersey, contain 1 to 5 percent TiO_2. These deposits are mined with floating suction or bucket-line dredges that handle up to 1000 megagrams of material per hour. The sand is treated by wet gravity methods that use spirals, cones, sluices, or jigs to produce a mixed, heavy-mineral, bulk concentrate. As many as five individual marketable minerals are separated from the bulk concentrate by a combination of dry separation techniques using magnetic and electrostatic (high-tension) separators, sometimes in conjunction with dry and wet gravity concentrating equipment (29). Figure 31 presents a composite flow diagram for extracting and beneficiating placer deposits containing rutile and ilmenite.

Ilmenite Rock (Lode) Deposits--

Ilmenite is being mined from a rock deposit in New York by conventional open-pit methods. This ilmenite/magnetite ore, which averages 18 percent TiO_2, is crushed and ground to a small particle size. The ilmenite and magnetite fractions are separated magnetically (the magnetite being more magnetic because of its greater iron content). The ilmenite sands are further upgraded in a flotation circuit. Figure 32 illustrates the mining and beneficiation of titanium from an open pit.

Waste Streams

Table 42 presents a summary of multimedia wastes generated by extraction and beneficiating of titanium ores. The following paragraphs refer to this table in discussing the air, liquid, and solid waste streams.

Air Emissions--

Fugitive dust emissions from the operations of an ilmenite rock (lode) open-pit mine are the major air emissions associated with titanium mining. The operations include overburden removal and ore blasting, loading, transport (fugitive dust from haul roads), and unloading. Although information is not available on emission rates from individual operations, overall uncontrolled fugitive emissions from open-pit mining are estimated to be 0.1 kilogram per megagram. Estimates indicate that hard rock mining produces particles averaging 5 microns in diameter and ranging from 0.5 to 10 micrometers (69). Of course, dredging of placer sand deposits does not produce particulate emissions.

Uncontrolled air emissions from benefication operations at open-pit mines are estimated to be 19 kilograms per megagram of

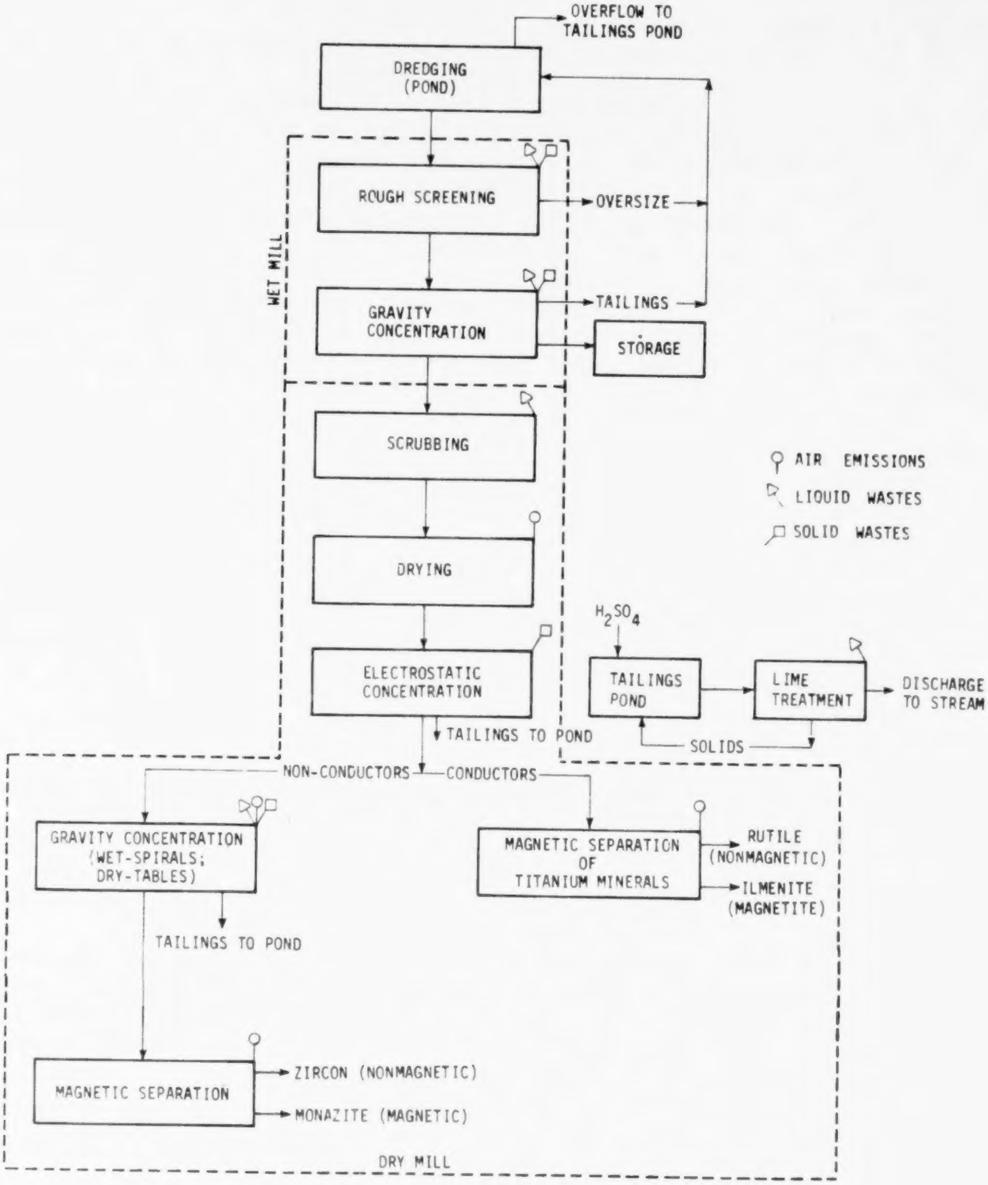
OVERFLOW TO TAILINGS POND
DREDGING (POND)
ROUGH SCREENING
OVERSIZE
WET MILL
GRAVITY CONCENTRATION
TAILINGS
STORAGE
SCRUBBING
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES
DRYING
H_2SO_4
ELECTROSTATIC CONCENTRATION
TAILINGS POND
LIME TREATMENT
DISCHARGE TO STREAM
TAILINGS TO POND
SOLIDS
NON-CONDUCTORS
CONDUCTORS
GRAVITY CONCENTRATION (WET-SPIRALS; DRY-TABLES)
MAGNETIC SEPARATION OF TITANIUM MINERALS
RUTILE (NONMAGNETIC)
ILMENITE (MAGNETITE)
TAILINGS TO POND
MAGNETIC SEPARATION
ZIRCON (NONMAGNETIC)
MONAZITE (MAGNETIC)
DRY MILL

Figure 31. Mining and beneficiating of heavy-mineral beach sand (placer) deposits.

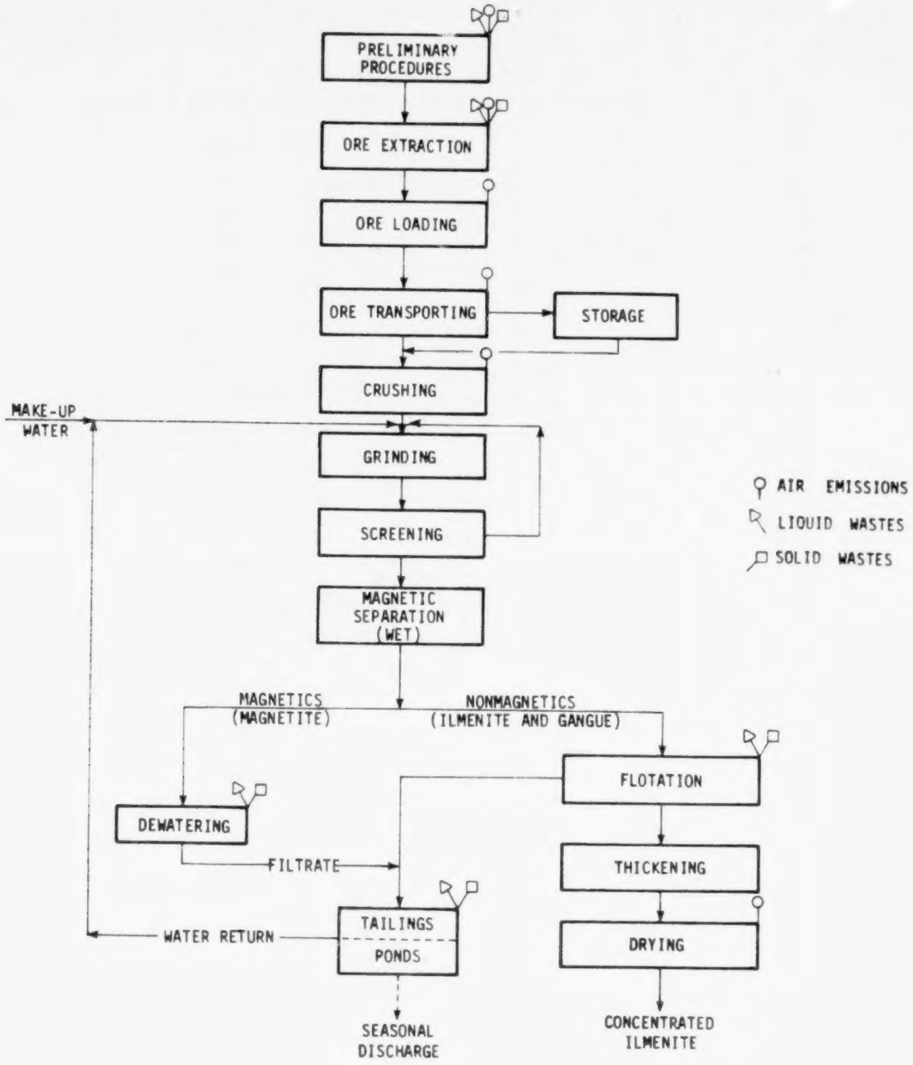
PRELIMINARY PROCEDURES
ORE EXTRACTION
ORE LOADING
ORE TRANSPORTING
STORAGE
CRUSHING
MAKE-UP WATER
GRINDING
SCREENING
MAGNETIC SEPARATION (WET)
MAGNETICS (MAGNETITE)
NONMAGNETICS (ILMENITE AND GANGUE)
FLOTATION
DEWATERING
FILTRATE
THICKENING
TAILINGS
PONDS
WATER RETURN
DRYING
SEASONAL DISCHARGE
CONCENTRATED ILMENITE
AIR EMISSIONS
LIQUID WASTES
SOLID WASTES

Figure 32. Mining and beneficiating of ilmenite rock (lode) deposits.

TABLE 42. SUMMARY OF MULTIMEDIA WASTES FROM MINING AND BENEFICIATING OF TITANIUM ORES

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
Overburden removal^a			Mine^a	TSS	14 mg/ℓ^d	Overburden removal^a	Topsoil, subsoil and other strata	
Ore extraction^a	Fugitive particulates	0.1 kg/Mg of ore		Oil and grease	3.0 mg/ℓ^d	Ore extraction^a	Gangue	Total solid waste generated at mine is 1.25 Mg/Mg of ore
Ore loading^a				Fluoride	3.2 mg/ℓ^d	Magnetite dewatering^a	Tailings	
Ore transporting^a				Total Kjeldahl nitrogen	2.24 mg/ℓ^d	Ilmenite flotation^a	Gangue	
				Nitrates	15.52 mg/ℓ^d	Rough screening^b	Hardpan and roots^g	Approximately 97 percent of total dredged material is returned to dredged area^h
Crushing^a			Mill^{a,e} (Concentrations of major constituents)	TSS	26,300 mg/ℓ^d	Gravity concentration^b (wet mill)	Tailings	
Drying^{a,b}	Particulates and combustion products	19 kg/Mg of ore^c		TOC	9.0 mg/ℓ			
				Ni	1.19 mg/ℓ^d			
				Ti	2.08 mg/ℓ	Gravity concentrations^b (dry mill)	Tailings	
Magnetic separation^b				Fe	500 mg/ℓ^d			
				V	2.0 mg/ℓ^d			
Dredging	Particulates	4.75 kg/Mg of ore^c		Cr	0.58 mg/ℓ^d			

(Continued)

TABLE 42. (Continued)

Air			Liquid			Solid		
Source	Pollutant	Uncontrolled emission rate	Source	Pollutant parameter	Uncontrolled discharge	Source	Pollutant	Uncontrolled quantity
			Raw mill wastewater[b,f] (Concentrations of major constituents)	Oil and grease	2.0 mg/ℓ[d]			
				Cu	0.43 mg/ℓ[d]			
				Zn	7.6 mg/ℓ[d]			
				Fluoride	32.5 mg/ℓ[d]			
				Mn	5.9 mg/ℓ[d]			
				TSS	209-11,000 mg/ℓ[d]			
				TOC	321-972 mg/ℓ[d]			
				COD	362-1338 mg/ℓ[d]			
				Oil and grease	40-400 mg/ℓ[d]			
				Ti	<0.2-0.40 mg/ℓ[d]			
				Fe	0.93-4.9 mg/ℓ[d]			
				Cr	<0.01-0.03 mg/ℓ[d]			
				Phosphate	0.35-0.40 mg/ℓ[d]			
				Total Kjeldahl nitrogen	0.65 mg/ℓ[d]			

[a] Ilmenite rock (lode) open-pit operations. Represents the one facility in U.S. (New York) which is currently operating.

[b] Placer deposit operations.

[c] Ref. 69. Order of magnitude estimation.

[d] Ref. 29. Load rates in kg/Mg of concentrate available in this source for mill effluents.

[e] This raw mill wastewater is treated at the New York facility by simple settling.

[f] Combined wet mill and dredge pond discharge. Typically treated by flocculation with sulfuric acid.

[g] Ref. 69 and inspection of Humphrey's Mining Company's Dredging operation (Boulogne, Florida) and dry mill (Folkston, Georgia) by R. Amick and J. Greber of PEDCo. January 1977.

material handled, whereas emissions from beneficiation of dredged material are estimated to be 4.75 kilograms per megagram (69). The primary sources of these emissions are the crushing operation at open-pit mining facilities and the drying operations at each type of mine. Particulate emissions from magnetic and electrostatic separation operations are insignificant compared with these sources. Storage of the ore in open piles can be another source of fugitive emissions.

Liquid Wastes--

Lode deposits--Considerable quantities of water (2760 cubic meters per day) are discharged from the open-pit ilmenite mine in New York. The water contains high concentrations of oils and greases, fluorides, Kjeldahl (organic) nitrogen, and nitrates (from nitrate-based explosives) (76). Table 42 lists the concentrations.

Dewatering of magnetite concentrates and ilmenite flotation also generates waste mill water at the New York open-pit facility. The raw wastewater stream from the flotation process amounts to about 35,000 cubic meters per day and contains large amounts of suspended solids and relatively high levels of iron, titanium, oil and grease, zinc, nickel, vanadium, and chromium. Table 42 lists the concentrations of the major constituents of the raw mill wastewater. Reagents used in the flotation circuit include tall oil, fuel oil, methyl amyl alcohol, sodium bifluoride, and sulfuric acid (29).

Placer deposits--Water used for gravity separation in wet mills at placer extraction facilities is discharged to a dredge pond. The sands contain organic materials which form a highly colored colloidal slime. In addition, high levels of phosphate and organic nitrogen are present in the raw waste streams. Waste lubricating oil from the dredge and wet mill and oversize from the screens are also dumped into the dredge pond.

Wastewaters from the scrubbing operations of the dry mill are a source of clay and other suspended solids. Tailings are disposed of in the gravity concentration operation of the dry mill, with subsequent discharge to a tailings pond or dredge pond, depending on the location of the dry mill (77).

The organic colloidal slime (formed when the organic materials in the placer bodies are disturbed) is comprised primarily of humates and tannic acid, which are the principal waste constituents of the dredge pond discharges. This is reflected in the high chemical oxygen demand (COD) (362 to 1338 milligrams per liter) and total organic carbon (TOC) (320 to 972 milligrams per liter) detected in the raw waste streams before treatment. High levels of phosphate and nitrogen are also present in the raw waste streams (see Table 42).

Solid Waste--

Considerable solid waste is generated at the New York open-pit facility. Approximately 1.25 megagrams of waste must be removed from the mine to obtain 1 megagram of ore (100). Tailings generated by the magnetic separators still contain ilmenite and are processed further by the flotation process. Gangue is routed from this process to the tailings pond. Similarly, the filtrate from dewatering the magnetite is disposed of in the tailings pond.

Overburden and gangue generated in the mining and wet milling of placer deposits goes directly back to the dredge pond. Tailings from the dry mills scrubbing and gravity separation operations are disposed of in the dredge pond or tailings pond, depending on the location of the dry mill.

Control Technology

Waste streams generated by the mining and beneficiation of titanium-bearing minerals are controlled by conventional methods.

Air Emissions Control--

Fugitive dust emissions from the New York open-pit mining operations are best controlled by the methods described in Section 3--wet suppresion, chemical suppression methods, and wind breaks. Fugitive dust emissions from truck traffic on haul roads is by far the most easily controlled via a conscientious watering/chemical additive program. Control efficiencies of 50 percent are attainable by this method. Dusting of open storage piles can also be controlled by wet suppression methods. Control of particulate emissions from open-pit beneficiating sources, trucking, and drying are best controlled by confinement, wet suppression, or water sprays (for crushing only), and a high-efficiency centrifugal collector. Control efficiencies of 90 percent are estimated for these sources, yielding a controlled emission factor of 1.9 kilograms per megagram (69).

Emission sources in the titanium ore dredging operations (drying, electrostatic concentration, and magnetic concentration) are controlled by methods similar to those applied to open-pit beneficiating operation sources, i.e., confinement and use of a fabric filter or high-efficiency centrifugal collector. Control efficiencies of 90 percent are estimated, yielding a controlled emission factor of 0.5 kilogram per megagram (69).

Liquid Waste Control--

Liquid wastes from the New York open-pit facility, generated primarily in the flotation circuit, are discharged to a formerly used open-pit quarry that serves as a tailings pond. Clarified overflow from this pit is recycled back into the mill circuit at the rate of 34,900 cubic meters per day with a makeup rate of 978 cubic meters per day (total mill water requirement is 35,772 cubic meters per day). The process water has an alkaline pH (69).

Discharges from the settling pond at a quarry pit occur seasonally when rain and resulting surface runoff exceed mill water makeup requirements. Before it is finally discharged, this water is briefly retained in a small pond. Treatment of mill effluent could be improved by diverting surface runoff away from the quarry pit (which results in almost no discharge) and increasing the retention time in the small secondary pond. Treatment with lime or some other precipitating agent also would ensure optimum metal and fluoride removal (69).

Concentrations of major constituents in treated recycle water from the settling pond (discharged to a stream during heavy rains) include iron (<0.03 milligram per liter--99+ percent removal), titanium (<0.2 milligram per liter--90 percent removal), oil and grease (2 milligrams per liter--no removal), zinc (<0.002 milligram per liter--99+ percent removal), nickel (<0.01 milligram per liter--90+ percent removal), vanadium (<0.5 milligram per liter-->75 percent removal), and chromium (0.02 milligram per liter--97 percent removal).

Liquid wastes from placer deposit milling operations are typically discharged to a dredge pond. If the dry mill is not located adjacent to the dredging wet mill, a separate tailings pond also is necessary. Discharge of wet mill effluent can be significant, i.e. as much as 12,000 cubic meters per day from one operation (69). Dredge pond effluent, which contains colloidal organic material of high coloring capacity, is treated in a series of three or four settling ponds. Sulfuric acid is added as a flocculant to reduce the pH to 3.5. Both acid and lime are fed automatically. Reagents are added to the waste streams in flumes designed to create turbulent mixing.

Two of the major constituents of settling pond effluent are concentrations of COD (13.5 milligrams per liter--96 percent removal) and TOC (5.5 milligrams per liter--97 percent removal).

Solid Waste Control--

Overburden from open-pit mining of titanium rock deposits is disposed of by filling in exhausted quarry areas, then grading. Provisions should also be made to landscape the exhausted mine site.

As discussed in the solid waste section, overburden and gangue generated in the mining and milling of placer deposits are typically disposed of in the dredge pond. If this dredging operation is improperly managed, it can devastate a large area of land. Reportedly some companies are carefully restoring land traversed by their dredges. Such restoration practices were observed at the Humphrey's Mining Company operations in Boulogne, Florida (dredging and wet milling) and Folkston, Georgia (dry milling).* These facilities stockpile the topsoil during site preparation operations and revegetate the area after it has been dredged and backfilled. Colloidal slimes from three settling ponds that treat discharge from the dredge pond are dried out in designated areas. These colloidal slimes, which contain 20 percent solids, are spread in 30-centimeter layers over areas of dried-up dredge pond tailings. After it dries to a 8-centimeter solid layer, it is dug up and plowed into an adjacent sandy area. The first two settling ponds are cleaned out every 30 to 60 days. Average flow rate through these treatment ponds is 2 to 4 cubic meters per minute and average retention time is about 5 days per pond.*

Conclusions and Recommendations

Waste streams generated by mining activities associated with hard rock (lode) and tracer deposits appear to be sufficiently controlled (or at least controllable) by conventional techniques, e.g., placer deposit operations typically return solid and conventionally treated liquid wastes to their point of origin, the dredge pond. Solid and liquid wastes generated by beneficiation also appear to be adequately controlled/controllable by conventional techniques. Beneficiating operations, particularly in open-pit mines, are a potential source of appreciable air emissions (TiO_2), even though they are 90 percent controlled; however, this control efficiency could easily be upgraded by applying such conventional methods as fabric filters.

Based on the above conclusions and the fact that the United States has less than 10 producers of titantium ore, research and development programs for this industry appear to be unnecessary. Sufficient solutions are available to handle any pollutant control problems that are likely to develop in titanium ore facilities.

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*Inspection of Humphrey's Mining Company's Dredging Operation (Boulogne, Florida) and dry mill (Folkstan, Georgia) by R. Amick and J. Greber of PEDCo.

SECTION 6

NONFERROUS METALS (REFINERY/SMELTER BY-PRODUCTS)

This section deals with several nonferrous metals that are not mined for their own economic value, but are recovered as smelter or refining by-products of ores that are mined for more economically attractive metals.

BISMUTH (95, 101)

Nearly all domestic bismuth is recovered as a by-product of lead smelting. Most bismuth resources are associated with copper, lead, and zinc ores in Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, and Utah. Other sources include electrolytic sludges and other metallurgical products from copper and zinc refineries, which are sent to lead refineries for separation and refining of other associated metals such as gold, silver, selenium, and platinum. Approximately one-half of the domestic requirement for refined bismuth is imported, primarily from Japan.

CADMIUM (95, 102)

Cadmium is recovered in the United States as a by-product of zinc ore smelting and refining. In 1974, however, more than one-half of U.S. demand was imported.

GALLIUM (95, 103)

Gallium is recovered as a by-product from processing aluminum and zinc ores. Although domestic resources are large, demand outstrips production and gallium must be imported, mostly from Canada and Switzerland. Recent increases in national demand are expected to result in expanded domestic operations and in the development of gallium as a by-product of other raw material sources.

GERMANIUM (95, 104)

U.S. production of primary germanium comes from the processing of domestic and foreign zinc smelter concentrates and from the reprocessing of scrap and foreign material. Imported germanium-containing zinc concentrates come primarily from Canada and West Germany.

HAFNIUM (95, 105)

Hafnium is found in association with the zirconium in zircon ore, which is recovered from titanium-bearing minerals as a coproduct or by-product. Although domestic resources of zircon are quite large, hafnium production depends on the demand for reactor-grade, hafnium-free zirconium. Zircon ore is contained in sand deposits in Florida, New York, and New Jersey, and is recovered by dredging.

INDIUM (95, 106)

U.S. indium is recovered as a by-product of smelting and refining zinc and lead ore. It is obtained by refining the residue and flue dusts from these smelters. About 75 percent of the national demand is met by imports of the metal or unprocessed concentrates, mostly from Canada.

SELENIUM (95, 107)

Domestic selenium is recovered principally from the anode slimes obtained from the electrolytic refining of copper In 1974, about 55 percent of the selenium used in the United States was imported.

TELLURIUM (95, 108)

Tellurium also is recovered from the anode slimes obtained from the electrolytic refining of copper. In recent years, about 75 percent of U.S. tellurium has come from domestic production. The remaining 25 percent has been imported, chiefly from Peru and Canada.

THALLIUM (95, 109)

All thallium recovered in the United States occurs as a by-product of the base metals mining industry, primarily zinc smelting. Since supply exceeds demand, collected zinc residues are now being stockpiled.

ZIRCONIUM (95, 105)

Zirconium is produced from zircon, which is a mineral recovered only as a coproduct or by-product of titanium mining. Zircon is used primarily as facing for foundry molds, particularly in the iron and steel industry, and a very small amount is used for the production of zirconium metal. If zirconium is to be used for nuclear purposes, hafnium must be removed (hafnium occurs in association with zirconium in zircon in varying ratios, averaging 1:50) to provide a reactor-grade product. In 1975 zirconium metal in the United States was produced largely from imported zircon ore.

SECTION 7

NONFERROUS METALS (NONDOMESTIC)

Section 7 deals with those nonferrous metals that are not presently recovered from domestic ores. Because these metals are imported either in a finished or semifinished form or are produced from imported raw ores, their extraction does not pose an environmental hazard within the United States.

ARSENIC (95, 110)

Arsenic is an undesirable minor by-product associated with ores mined chiefly for copper, gold, and lead, and it must be removed to minimum levels when refining these metals. Arsenic recovery depends on the efficiency of base-metal smelter flue dust treatment. The U.S. demand for arsenic is met largely by the processing of imported base metal ores.

The disposal of arsenical materials at base metal smelters presents a solid waste disposal problem, particularly in relation to soil and water pollution. Environmental problems related to underground mining of arsenic-bearing ores are similar to those related to base metal mining. Also, arsenic in sulfide minerals that are exposed to the atmosphere may form soluble arsenates, which can cause surface and groundwater pollution.

CESIUM (95, 111)

No cesium is mined in the United States; therefore, all cesium raw material is imported, primarily from Canada. Although cesium ore was once mined in Maine and South Dakota, future extraction of significant quantities in the United States is unlikely

PLATINUM-GROUP METALS (95, 112)

Platinum, palladium, iridium, rhodium, ruthenium, and opmium makeup the platinum-group metals. About 9 percent of total domestic demand is produced in the United States, principally as a by product of copper smelting. Platinum group metals have also been obtained by dredging placer deposits of the Salmon River in the Alaskan Goodnews Bay District, but this source was closed indefinitely in early 1976. Production had been declining for years (in 1974 only 0.3 percent of the total U.S. demand came from this source). More than 90 percent of the domestic demand is met by imports. South Africa, Russia, and Canada supply the greater portion.

Since most U.S. mine production of platinum-group metals is recovered as a by-product of copper mining and refining, environmental problems are incidental to copper production.

RADIUM (95, 113)

Radium is present in small amounts in uranium ore and the geology of radium and uranium are the same. Radium-226 is the commercial radioactive decay product of uranium-238, the most abundant uranium isotope. The United States has not mined radium since 1950.* At one time radium was recovered from high-grade uranium deposits in Colorado.

RUBIDIUM (95, 114)

Rubidium is not mined in the United States. Domestic rubidium and its compounds are obtained from the residues remaining from the processing of lepidolite for lithium compounds. Commercially productive residues containing rubidium are likely to be exhausted in the near future, and future domestic recovery will probably come from residues resulting from the processing of imported pollucite for cesium.

SCANDIUM (95, 115)

The supply of scandium in the United States has come from sporadic domestic production, reprocessed uranium residues, and irregular imports. Data on these sources are not available.

TIN (95, 116)

The United States has no commercially significant tin mines; however, a very small amount of tin is recovered from placer deposits in Alaska and New Mexico and as a by-product of molybdenum at the Climax Mine in Colorado. These sources are expected to remain negligible in the foreseeable future, and virtually all primary tin requirements will be met by imports.

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*Telephone conversation between R. Amick of PEDCo and Ms. M. Kahn, Bureau of Mines, Pittsburgh, Pennsylvania. April 1977.

APPENDIX

EXPLANATION OF GUIDANCE CRITERIA FOR ESTABLISHING R&D PRIORITIES

As stated in the Summary, criteria that may be used to establish R&D priorities are arranged in Table 1 according to their relative importance in defining possible research and development efforts. The generation of hazardous waste by any industry is assumed to be the criterion of prime importance because of the environmental threat (lethal or sublethal) posed if such wastes are not controlled. Control of nonhazardous atmospheric emissions and liquid and solid wastes is considered necessary in the mining industry; however, the environmental threat of these wastes is not of the magnitude as that from hazardous wastes. Thus, values applied to hazardous waste are higher than those applied to nonhazardous waste.

The quantity of ore mined by a particular industry is also a criterion because the amount of ore mined is directly related to the amount of waste generated by that industry. A review of the industries covered in this study reveals that there are three distinct size classes of ore production. (See Table 1.)

The future of each industry is also important in determining research and development needs. If projections indicate that an industry is to decline in the future, the need for research and development is less; whereas projected increases in an industry indicate more waste materials will be generated and improved control of the waste materials will be required.

The number of domestic mines, principal producing states, and the total number of producing states are important criteria in that the wider the geographic distribution of an industry, the more widespread will be the pollution problems associated with that industry and the greater need for control.

The degree of information available on each industry is a necessary criterion for several reasons. Lack of understanding regarding an industry's process means a lack of knowledge about its waste streams, and the less that is known about the waste streams, the greater the possibility that hazardous and non-hazardous waste streams are either inadequately controlled or completely uncontrolled.

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